

Report No. UT-15.11

## **IDENTIFYING CHARACTERISTICS OF HIGH RISK INTERSECTIONS FOR PEDESTRIANS AND CYCLISTS: PHASE 2**

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### **Submitted By:**



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## **LIST OF ACRONYMS**

|        |  |
|--------|--|
| AASHTO | American Association of State Highway and Transportation Officials |
| BCI    | Bicycle Compatibility Index  |
| BLOS   | Bicycle Level-of-Service   |
| CDC    | Centers for Disease Control  |
| FHWA   | Federal Highway Administration                                     |
| GIS    | Geographic Information System                                      |
| MAG    | Mountainland Association of Governments                            |
| UDOT   | Utah Department of Transportation                                  |
| UTM    | Universal Transverse Mercator                                      |
| WFRC   | Wasatch Front Regional Council                                     |

## **EXECUTIVE SUMMARY**

While the transportation network is meant to accommodate a variety of transportation modes, the experience varies for the users of each mode. For example; an automobile, cyclist, transit rider, and pedestrian will all have a very different experience traveling along the same corridor. Often, the physical characteristics of the system that make travel easier or more enjoyable for one mode may produce challenges or increase risk for users of another mode. These heightened risks are most common at intersections and are especially relevant for users of active transportation modes, such as pedestrians and cyclists.

Using bicycle and pedestrian crash data from Weber, Davis, and Utah Counties (2006-2012) alongside a comprehensive site inventory of built environment characteristics this research identifies:

- Which intersections have the highest rate of accidents for cyclists and pedestrians?
- Do high accident intersections exhibit any characteristics that are significantly different from low-accident intersections?
- Do areas with specific demographics experience more/less bicycle and pedestrian accidents (e.g. a large percentage of young people)?
- What physical characteristics make intersections more dangerous for cyclists and pedestrians?

This analysis addresses many of the characteristics and issues concerning differences between high- and low-risk intersections for pedestrians and cyclists, by identifying which characteristics are the most significant at predicting crash rates. While the high- and low-risk intersections seem to have an even spatial dispersion throughout the study area (with some corridor clustering), this research showed that high-risk and low-risk intersections do differ significantly in several ways.

First, high-risk intersections are significantly wider than low-risk intersections. On average a high-risk intersection has an additional 14 feet of width. This additional width requires more time for non-motorized travelers to cross and could result in a failure to clear the intersection by the time the signal changes. High-risk intersections also have more through lanes than their low-risk counterparts. Given these data the next significant factor should come as no

surprise. Shorter signal lengths (green light times) result in a higher rate of non-motorized crashes. Each additional 10 seconds of green light time results in 1.3 fewer non-motorized crashes. Taken in context a wider street with more through lanes is more dangerous to cross, and the likely culprit is that the signal time does not leave a pedestrian or cyclist with an adequate window to safely clear the intersection. Additionally, as the number of green turn arrows at an intersections increased the number of non-motorized crashes increased dramatically. For each additional green arrow present in intersections in this sample, there was an increase of 5.47 non-motorized crashes. Finally, high-risk intersections exhibit a larger number of non-residential driveways within 100 meters of the intersection. Low-risk intersections had an average of 4 fewer non-residential driveways within 100 meters.

An analysis of demographics showed no significant correlation to crash rates for either aggregate or specific active modes. While there was some variation in the demographics at high-risk versus low-risk intersections, the differences were not significant. Additionally, only one built-environment characteristic was significantly correlated to impact on the number of non-motorized crashes represented in this sample. Intersections located in mixed-use developments experienced significantly fewer pedestrian crashes than intersections surrounded by residential or commercial land-uses.

Lastly, a parallel regression analysis of elasticities found that the presence of non-motorized crashes during construction at a given intersection significantly predicted an increase in aggregate non-motorized accidents, as well as predicting a significant increase in cyclist incidents. This implies that the presence of construction creates a significant hazard for non-motorized modes, specifically for cyclists.

Based upon the analysis conducted in this study, the following recommendations are being made:

- Evaluate signal timing to better accommodate intersection width;
- Reduce conflicts on green arrows by avoiding left turn parallel path crashes; and

- Consider limiting the number of non-residential access points in the upstream functional area of an intersection (based on Utah's Administrative Code R930-6: Access Management)

## **1.0 INTRODUCTION**

### **1.1 Problem Statement**

While the transportation network is meant to accommodate a variety of transportation modes, the experience varies for the users of each mode. Often, the physical characteristics of the system that make travel easier or more enjoyable for one mode may produce challenges or increase risk for users of another mode. Active travelers, such as cyclists and pedestrians, are often faced with an increased risk due to their limited protection and increased vulnerability, especially at intersections where they are most likely to come in contact with motor vehicles.

### **1.2 Objectives**

This research builds upon a 2012 pilot study conducted in Salt Lake County and seeks to further determine what characteristics make intersections more dangerous for cyclists and pedestrians. Similar to the pilot study, this research first identifies intersections with high rates of active mode crashes and injuries in the three additional counties that comprise Utah's Wasatch Front (Weber, Davis, and Utah Counties). Next a thorough analysis of the physical characteristics of the high-risk intersections is conducted and any differences from intersections that have fewer active mode crashes are identified. By identifying the characteristics that make an intersection dangerous for active modes, UDOT can be better informed regarding which negative characteristics to avoid when designing new intersections while also working to make appropriate changes to existing intersections to improve safety for cyclists and pedestrians across Utah.

### **1.3 Scope**

Using bicycle and pedestrian accident data from Weber, Davis, and Utah Counties (2006-2012) alongside a comprehensive site inventory of built environment characteristics this research identifies the following:

- Which intersections have the highest rate of accidents for cyclists and pedestrians?

- Do high accident intersections exhibit any characteristics that are significantly different from low-accident intersections?
- Do areas with specific demographics experience more/less bicycle and pedestrian accidents (e.g. a large percentage of young people)?
- What physical characteristics make intersections more dangerous for cyclists and pedestrians?

By answering these questions, this report identifies characteristics that contribute to or detract from bicycle and pedestrian safety at intersections, and provides recommendations for site improvements based on the analysis.

## **1.4 Outline of Report**

This report is organized according to the following sections. Section 2 provides a brief literature review examining the impacts that the built environment has on bicycle and pedestrian safety, specifically at intersections. Section 3 outlines the research methods employed in this work including a description of the study area and justifications. Section 4 presents the data collected for this study and provides summary characteristics for each of the intersections included in the analysis as well a discussion of local demographics and level of service variables. Section 5 presents both qualitative and quantitative analysis comparing high-risk and low-risk intersections including relationships between the intersections' characteristics (i.e. surrounding demographics, level of service, built environment, presence of construction, etc) and accident rates, as well as analyzing correlations between intersection characteristics and accident severity. Section 6 provides conclusions based upon the data provided in the previous sections and Section 7 outlines the author's recommendations for implementation.

## **2.0 RESEARCH METHODS**

### **2.1 Overview**

This section provides a brief overview of the existing research literature regarding intersection characteristics and bicycle and pedestrian safety.

### **2.2 Bicycle and Pedestrian Safety**

Pedestrians killed in traffic crashes accounted for nearly 15 percent of all traffic fatalities and 69,000 injuries in 2011. An additional 48,000 injuries and 677 fatalities were reported for cyclists (NHTSA, 2011). In 2009, Utah had 19 pedestrian fatalities accounting for approximately 7.8% of all state traffic crash fatalities, while cyclist fatalities accounted for an additional 2% (NHTSA 2009). Automobiles alone cannot be blamed for pedestrian and cyclist fatalities. Research has shown that both motorists and cyclists/pedestrians are frequently observed committing “road-rule violations” at intersections leading to an increase in safety risks (Cinnamon, Schuurman, and Hameed 2011), and most bicycle crashes at intersections occur as a result of failure to yield (Schepers, et al 2010). Additionally, there are two vulnerable populations when it comes to bicycle and pedestrian crashes; the young (ages 18 and under) and the elderly (ages 65+). Pedestrians in these two groups alone account for over 26% of traffic crash fatalities (NHTSA 2009). Children are especially vulnerable because they are often “exposed to traffic conditions that exceed their developmental and sensory abilities and their parents often overestimate their abilities (Dukehart, et al 2007, pp 6)”. Over 10% of all cyclists killed in 2011 were between the ages of 5 and 15 years old (NHTSA, 2011). A recent CDC study reported that one of the top reasons parents do not let their children walk to school is concerns about traffic (Dukehart, et al 2007). The evidence shows that cycling and walking can be dangerous forms of transportation, as the user is more vulnerable than someone traveling in a motor vehicle. The question then becomes, what factors make the environment more dangerous for pedestrians and cyclists?

## 2.3 The Impact of the Built Environment

The U.S. Department of Transportation's (USDOT) policy is to "provide safe and effective pedestrian accommodation wherever possible (FHWA safety Program 2011, pp 1)", however, in reality most local municipalities do not have the funding to provide adequate infrastructure for all users on all roads, nor would it make practical sense to do so. Approximately 24% of all non-motorist involved accidents in 2008-2009 (including 59% of bicycle injuries) took place in intersections (NHTSA 2011), and accidents occurring at intersections have been shown to be more severe for cyclists and pedestrians than those occurring mid-block (Zahabi, et al 2011). However, accidents involving pedestrians and cyclists rarely occur repeatedly in the exact same locations making it difficult to determine not only what circumstances lead to these crashes, but what could be done to prevent them in the future. Several studies have been conducted in an attempt to identify dangerous characteristics at intersections, as a way to reduce the risk faced by active travelers.

Existing research has shown that a number of key characteristics play a significant role in increasing the risk a pedestrian or cyclist faces at any given intersection. They include:

- Traffic volume (Miranda-Moreno, Morency, and El-Geneidy 2011; Miranda-Moreno, Strauss, and Morency 2011; Schneider, et al 2010; and Singh, et al 2011)
- Land-use mix (Miranda-Moreno, Morency, and El-Geneidy 2011; Schneider, et al 2010; Zahabi, et al 2011)
- Dedicated right turn lanes (Burbidge, 2012; Schneider, et al 2010)
- Presence of non-residential driveways within 50 feet of an intersection (Schneider, et al 2010)
- Percent of residents under age 18 living within a ¼ mile of the intersection (Schneider, et al 2010)
- Intersection width and number of through lanes (Singh, et al 2011)
- Signal cycle time (Singh, et al 2011), and
- Presence of bike lanes (Singh, et al 2011)

Although research has shown that there are specific components that can make some intersections more dangerous than others, a majority of cities and regions are still using a simplistic bike-ped infrastructure approach to improving bicycle and pedestrian safety, rather than addressing intersection characteristics more holistically. For example the United Kingdom

Department of Transport recently created a management strategy to help minimize cyclist and pedestrian risks, it includes: reducing traffic speeds and volumes; providing intersection treatments, traffic management, and hazard site treatments; improving carriageways (sidewalks); providing bike lanes; and converting footpaths to shared-use cycle paths (Singh, et al 2011). Of these strategies, only traffic volumes have been shown to significantly impact cyclist and pedestrian safety. This business-as-usual approach to planning may have long term consequences when it comes to the safety of active mode users.

## **2.4 Summary**

While the specific characteristics above have been identified as factors affecting pedestrian and cyclist safety at intersections in a variety of studies and locations across the country and world, there is little data available regarding traffic safety in Utah, and more specifically along the Wasatch Front. The following sections will provide an analysis of data gathered in this region to help local transportation planners focus on strategies to improve bicycle and pedestrian safety and to avoid installing infrastructure or making roadway and intersection “improvements” that may in fact be hazardous to pedestrians and cyclists.

## **3.0 DATA COLLECTION**

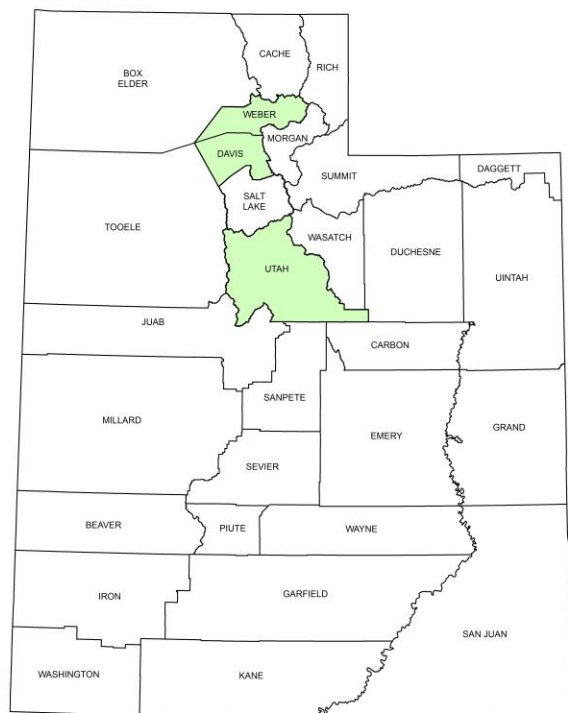
### **3.1 Overview**

The following section provides a complete discussion on the data analyzed in this report as well as presenting an overview of descriptive characteristics for each of the sites included in the analysis. This section provides data on which intersections were selected for analysis, a summary of their characteristics, a description of local demographics surrounding these locations, a discussion of intersections construction timelines, and a description and discussion regarding different measures for bicycle compatibility and level of service.

### **3.2 Study Area**

The analysis described in this report takes place in Weber, Davis, and Utah Counties (highlighted in Figure 1). These three counties make up the bulk of the land area along Utah's Wasatch Front (3,023 square miles), the urbanized area containing both the Salt Lake-Ogden and Provo Metropolitan Areas. These counties also contain 37 percent of Utah's population (U.S. Census, 2010).

This analysis builds on a prior pilot study of Salt Lake County to complete an analysis for the remainder of the Salt Lake Metropolitan Region. It is anticipated that additional work will be completed subsequent to this research to examine the less urbanized and rural areas of the state.



**Figure 1. Project Study Area**

### 3.3 Intersection Data Collection

Crash data for Weber, Davis, and Utah Counties was acquired from the Utah Department of Transportation's (UDOT) Traffic and Safety Division<sup>1</sup>. The data file included a list of the 3,464 crashes that occurred in Weber, Davis, and Utah Counties between 2006 and 2012 involving at least one pedestrian or cyclist, and provided information on the location (UTM coordinates), date, time, number of persons involved, traveler type (motorist, cyclist, pedestrian, etc.), and crash severity. The data were imported into a Geographic Information System (GIS) database in order to spatially identify locations with a high frequency of crashes occurring during the designated time period. Because street location was not specifically identified until 2009 (prior to that crashes were recorded by mile marker) the data from 2006-2008 were geo-coded to align with exact street addresses. Using spatial analysis techniques (available in ArcView 10.1) intersections were sorted according to the number of accidents that took place.

After identifying high- and low-risk intersections (described below in Section 3.4.1), a comprehensive inventory was conducted for each site, including both intersection specific transportation system characteristics (signal timing, presence of turn lanes, pedestrian countdowns, etc.) as well as built environment and urban form characteristics (land-use, sidewalks, curb radius building setbacks, presence of street trees, local transit access, etc.). Table 1 below shows a complete list of the characteristics included in the inventory. It is important to note that the characteristics included in this analysis were identified based upon the literature described in Section 2, the expertise of several local consultants and UDOT staff members, and lessons learned from the Salt Lake County Pilot Study.

Data for each of these characteristics was collected using a combination of field visits and aerial photograph analyses/evaluations. Each intersection was visited in person at least one time to conduct precision measurements as well as to acquire on site pedestrian and cyclist volume counts.

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<sup>1</sup> Crash data and analysis presented herein are protected under 23 USC 409

**Table 1. Intersection Inventory Characteristics**

| <b>Transportation System Characteristics</b> | <b>Built Environment Characteristics</b>  | <b>Other Data</b>                |
|--|---|----------------------------------|
| # of Roadway Legs (out of 4)                 | # Sidewalks                               | Median income (within ¼ mile)    |
| Speed Limit                                  | Sidewalk Widths                           | % population <18 (within ¼ mile) |
| Level of Service                             | Curb Radius                               | % population <65 (within ¼ mile) |
| Number of Lanes                              | Pedestrian Approaches (#)                 |                                  |
| Road Width                                   | Land-Use (Res, Comm, Mixed)               |                                  |
| Bike Lanes                                   | Street Trees                              |                                  |
| Signals (light, stop sign, etc.)             | Building Set Back                         |                                  |
| Signal Timing                                | Bus stops (within ¼ mile)                 |                                  |
| Dedicated Left Turn Lane (#)                 | Non-Residential Driveways (within ¼ mile) |                                  |
| Dedicated Right Turn (#)                     | Rail Stops (within ¼ mile)                |                                  |
| Raised Center Median (#)                     | Trails (within ¼ mile)                    |                                  |
| # of Through Lanes                           | Freeway on/off ramps (within ¼ mile)      |                                  |
| Crosswalk (#)                                |   |                                  |
| Pedestrian signals (#)                       |   |                                  |
| Pedestrian Signal Timing                     |   |                                  |

The following sub-sections summarize the data collected through the intersection inventories as well as qualitative and quantitative analyses comparing the high-risk and low-risk intersections. All inventory data presented in the tables was acquired through the author's on site inventories and measurements unless otherwise cited.

### **3.4 High-Risk and Low-Risk Intersections**

#### **3.4.1 Identifying High- and Low-Risk Intersections**

The first goal of this report was to identify which intersections in Weber, Davis, and Utah Counties were the most dangerous for pedestrians and cyclists during the given time period (2006-2012). Originally the analysis sought to identify the 10 most dangerous intersections for pedestrians and cyclists in each county, but a substantial drop-off in crash rates resulted in only 9 being selected for Utah County, for a total of 29 high-risk intersections. Table 2 below shows the coordinates of the intersections in each county with the highest frequency of cyclist and pedestrian crashes, as well as the number of crashes that occurred during the given time period and the intersection's municipal location within the county.

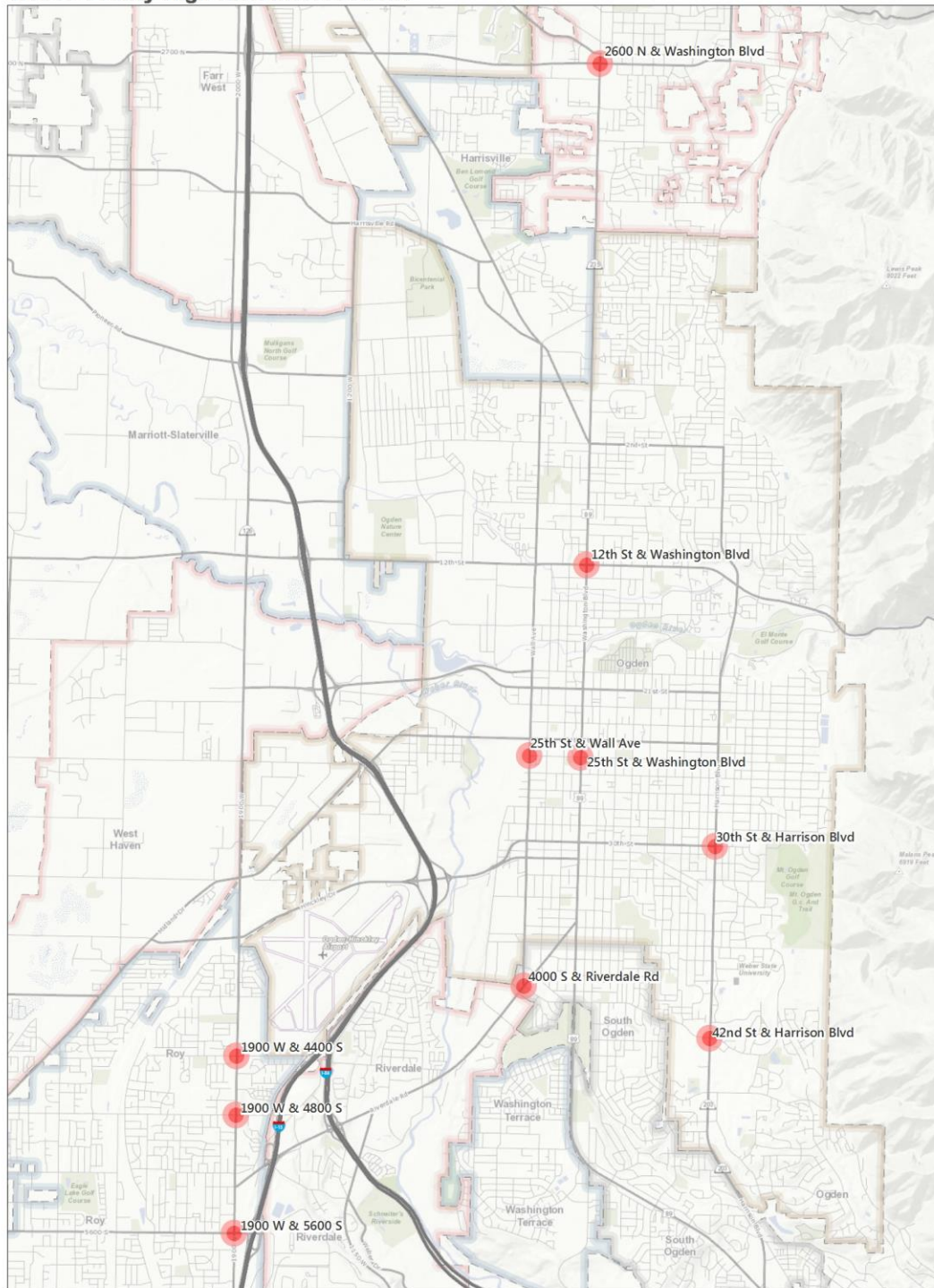
**Table 2. High-Risk Intersections**

| Intersection Coordinates            | # Bike-Ped Crashes* | City          | County |
|-------------------------------------|---------------------|---------------|--------|
| 12th St. Washington Blvd            | 12                  | Ogden         | Weber  |
| 1900 West 5600 South                | 8                   | Roy           | Weber  |
| 4000 South Riverdale Rd.            | 8                   | Riverdale     | Weber  |
| 25th St. Washington Blvd            | 8                   | Ogden         | Weber  |
| 25th St. Wall Ave                   | 7                   | Ogden         | Weber  |
| 1900 West 4400 South                | 7                   | Roy           | Weber  |
| 1900 West 4800 South                | 7                   | Roy           | Weber  |
| 42nd St. Harrison Blvd              | 6                   | Ogden         | Weber  |
| 30th St. Harrison Blvd              | 6                   | Ogden         | Weber  |
| 2600 North Washington Blvd          | 6                   | North Ogden   | Weber  |
| Antelope Dr. Hillfield Rd.          | 18                  | Layton        | Davis  |
| 500 South 200 West                  | 12                  | Bountiful     | Davis  |
| 700 South State St                  | 12                  | Clearfield    | Davis  |
| 2600 South Hwy 89                   | 11                  | Bountiful     | Davis  |
| 500 South Main St                   | 11                  | Bountiful     | Davis  |
| Hillfield Rd. and Main St.          | 10                  | Layton        | Davis  |
| Antelope Dr. University Park Blvd.  | 10                  | Layton        | Davis  |
| 2000 West Antelope Dr. (1700 South) | 9                   | Syracuse      | Davis  |
| 1000 West Antelope Dr. (1700 South) | 9                   | Syracuse      | Davis  |
| 300 North Main St.                  | 9                   | Clearfield    | Davis  |
| Bulldog Blvd and University Ave.    | 17                  | Provo         | Utah   |
| State St. and Center St.            | 16                  | Orem          | Utah   |
| 800 South State St.                 | 14                  | Orem          | Utah   |
| 200 North West State St.            | 13                  | American Fork | Utah   |
| Bulldog Blvd and Hwy 89             | 13                  | Provo         | Utah   |
| Freedom Blvd and Bulldog Blvd       | 13                  | Provo         | Utah   |
| 1500-1600 South Center St.          | 11                  | Orem          | Utah   |
| 1720 North State St.                | 11                  | Orem          | Utah   |
| 800 North University Ave.           | 10                  | Provo         | Utah   |
| <b>Total=</b>                       | <b>234</b>          |               |        |

\*This total includes all crashes involving at least one cyclist or pedestrian that took place within 100 feet of the listed intersection between 2006-2012 (Source: UDOT Safety Division)

High-risk intersections are spread throughout each county; however, there are several noticeable clusters. In Weber County three high-risk intersections are conspicuously close together along 1900 West in Roy. There is also a presence of high-risk intersections along Washington Boulevard in Ogden, however they are spaced significantly further apart. In Davis County nearly half of the high-risk intersections are located on Antelope Drive (4). Additionally, two are located within blocks of each other on 500 South in Bountiful. High-risk intersections in Utah County are located along two main corridors; State Street in Orem (4) and Bulldog Boulevard in Provo (3). Figures 2, 3 and 4 below show the spatial distribution of High-risk intersections by county.

## **Weber County High-Risk Intersections**



**Figure 2. High-Risk Intersections, Weber County**

### Davis County High-Risk Intersections



Figure 3. High-Risk Intersections, Davis County

### Utah County High-Risk Intersections

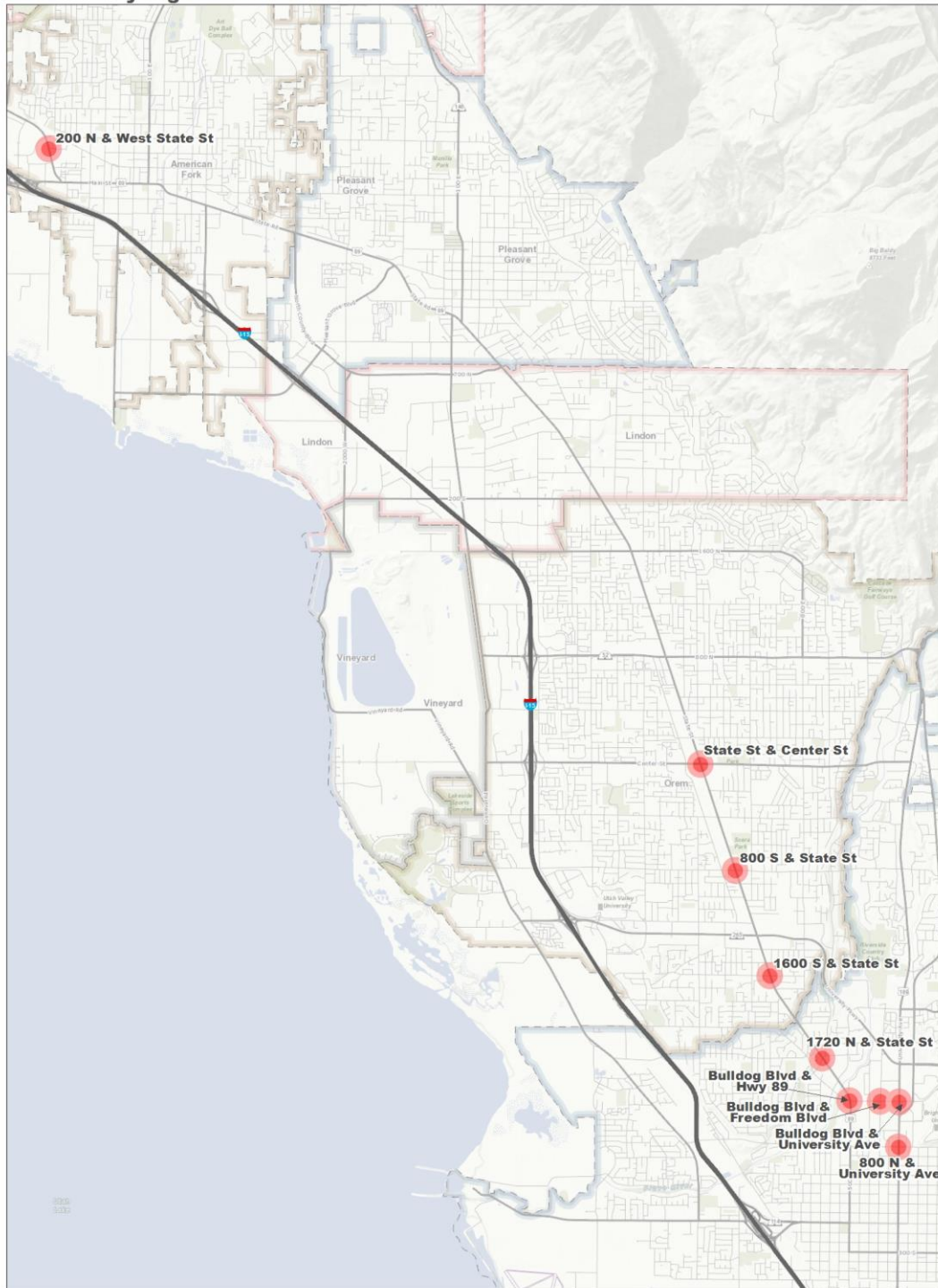


Figure 4. High-Risk Intersections, Utah County

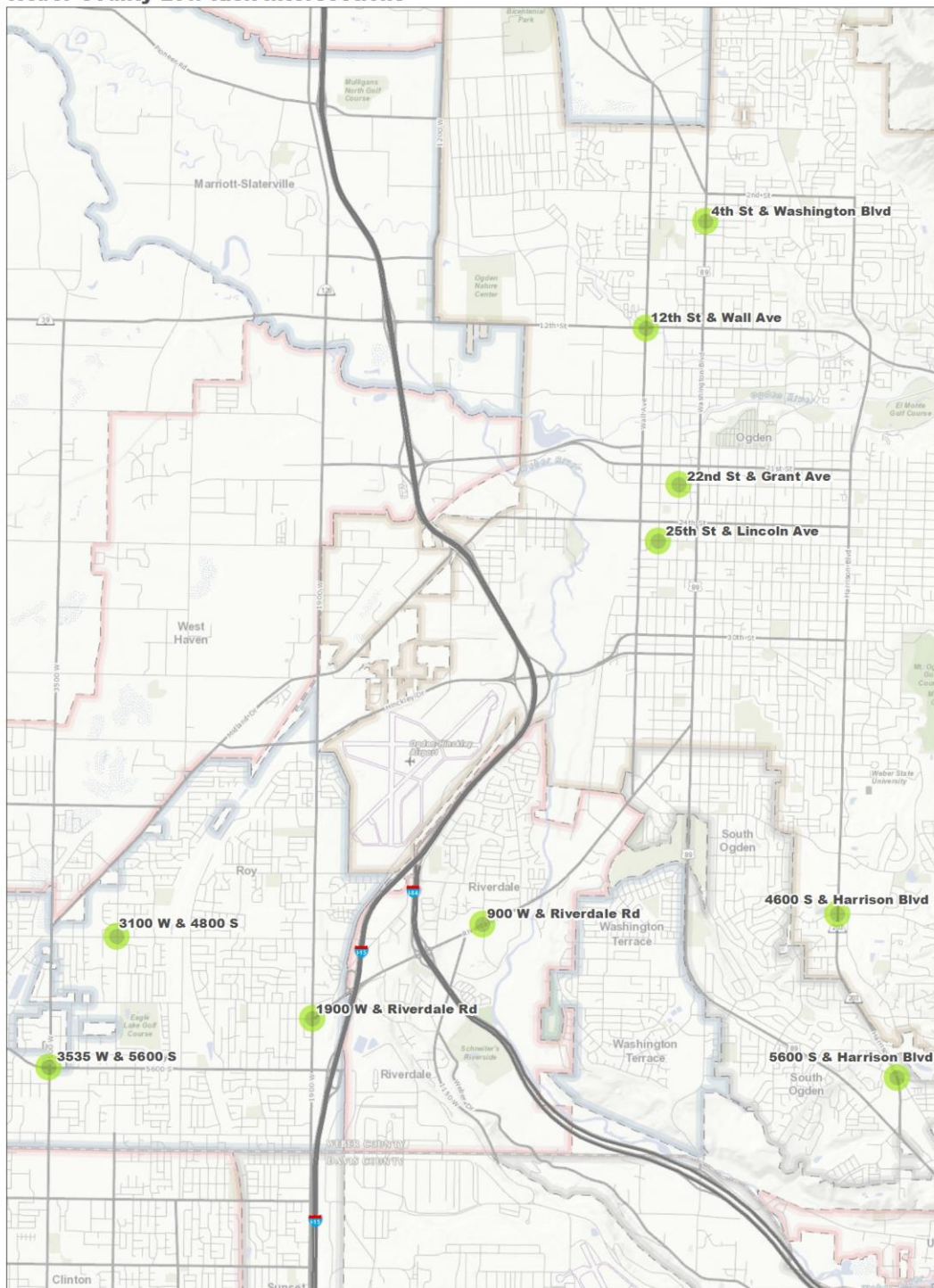
Because the second research question in this study seeks to determine how the physical characteristics of high-risk intersections differ from intersections with low crash rates, a second sample of low-risk intersections is required. Using the GIS database described in Section 3.3, ten intersections were selected that exhibited both low crash rates, as well as comparable site and situation characteristics to the high-risk intersections (although built environment characteristics will differ). Table 3 shows the coordinates for the low-risk intersections, as well as the number of crashes that occurred during the study period, and the intersection's municipal location within the county. Figures 5, 6, and 7 below show the spatial distribution of Low-risk intersections in each county.

**Table 3. Low-Risk Intersections**

| <b>Intersection Coordinates</b>   | <b># Bike-Ped Crashes*</b> | <b>City</b> | <b>County</b> |
|-----------------------------------|----------------------------|-------------|---------------|
| 4600 South Harrison Blvd          | 3                          | Ogden       | Weber         |
| 12th St. Wall Ave                 | 3                          | Ogden       | Weber         |
| 25th St. Lincoln Ave              | 2                          | Ogden       | Weber         |
| 3535 West 5600 South              | 1                          | Roy         | Weber         |
| 1900 West Riverdale Rd. (5300 S.) | 0                          | Roy         | Weber         |
| 3100 West 4800 South              | 0                          | Roy         | Weber         |
| 5600 South Harrison Blvd          | 0                          | Ogden       | Weber         |
| 900 West Riverdale Road           | 0                          | Riverdale   | Weber         |
| 4th St. Washington Blvd           | 0                          | Ogden       | Weber         |
| 22nd St. Grant Ave                | 0                          | Ogden       | Weber         |
| 1225 North Hillfield Rd           | 3                          | Layton      | Davis         |
| Antelope and Woodland Park Blvd   | 3                          | Layton      | Davis         |
| 500 South 500 West                | 3                          | Bountiful   | Davis         |
| Parrish Lane 400 West             | 2                          | Centerville | Davis         |
| 200 North Main St                 | 2                          | Kaysville   | Davis         |
| Gordan Ave and Fairfield Rd       | 2                          | Layton      | Davis         |
| 1000 East 1700 South              | 2                          | Layton      | Davis         |
| 1800 South Orchard Blvd           | 0                          | Bountiful   | Davis         |
| 300 North 2000 West               | 0                          | Clearfield  | Davis         |
| 1000 West 800 North               | 0                          | Clearfield  | Davis         |
| 1600 North State St               | 4                          | Orem        | Utah          |
| 400 South State St.               | 4                          | Orem        | Utah          |
| University Pkwy and Main St.      | 4                          | Orem        | Utah          |
| 500 West 940 North                | 3                          | Provo       | Utah          |
| 1850 N. State St                  | 2                          | Provo       | Utah          |
| 800 North 800 East                | 2                          | Orem        | Utah          |
| Bulldog Blvd and Canyon Rd.       | 1                          | Provo       | Utah          |
| Main St. and State St.            | 1                          | Lehi        | Utah          |
| University Ave Center Street      | 1                          | Provo       | Utah          |
| <b>Total=</b>                     | <b>48</b>                  |             |               |

\*This total includes all crashes involving at least one cyclist or pedestrian that took place within 100 feet of the listed intersection from 2006-2012 (Source: UDOT Safety Division)

# Weber County Low-Risk Intersections



**Figure 5. Low-Risk Intersections, Weber County**

### Davis County Low-Risk Intersections



Figure 6. Low-Risk Intersections, Davis County

### Utah County Low-Risk Intersections

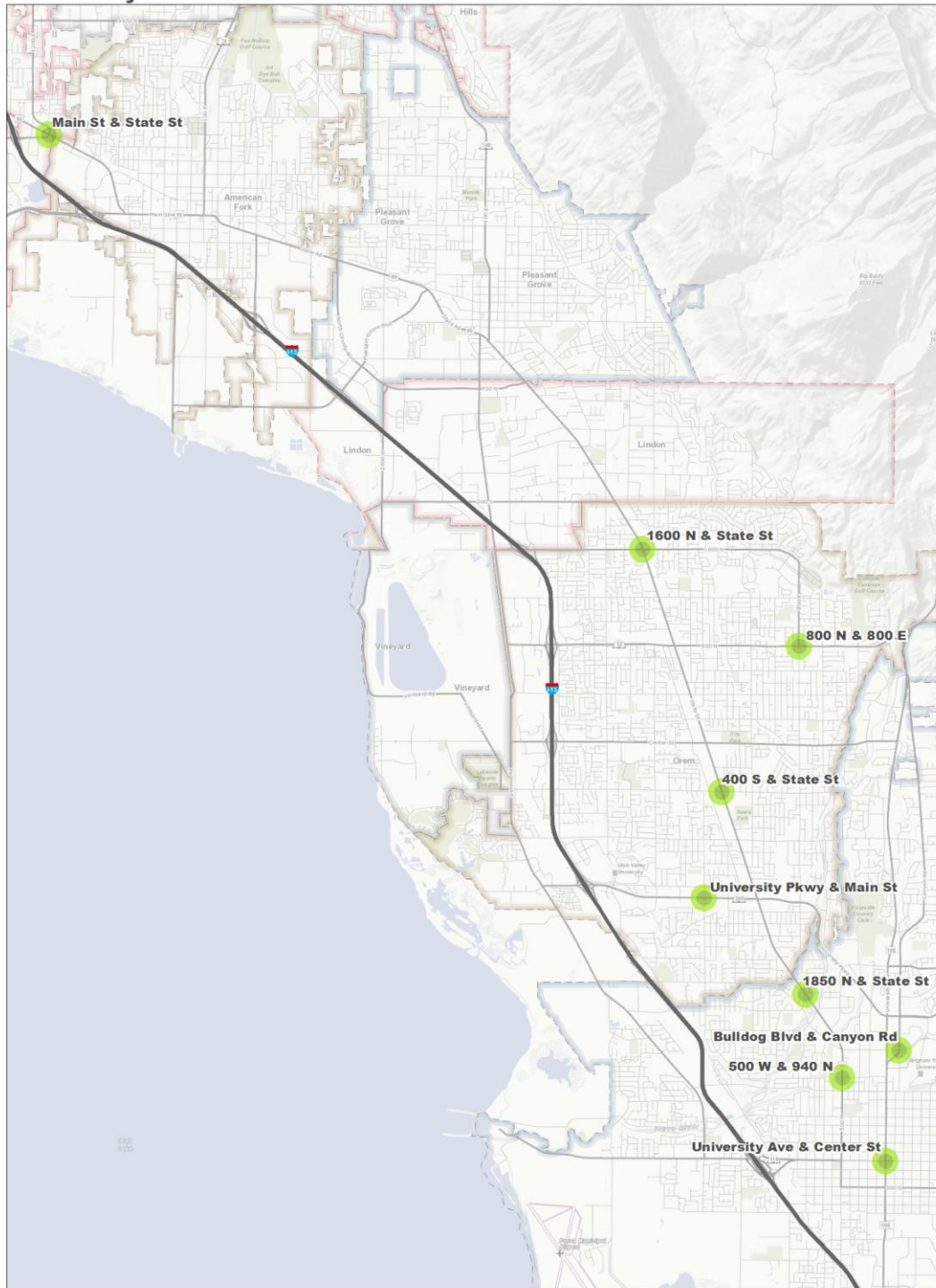


Figure 7. Low-Risk Intersections, Utah County

### 3.4.2 Intersection Characteristics

A summary analysis of inventory data revealed distinct differences between basic intersection characteristics of the high- and low-risk intersections. As shown in Table 4 below, high-risk intersections had a higher average speed limit, wider street width, and had a higher number of non-residential driveways nearby. It should be noted that this simplistic “heads-up” summary evaluation does not represent significance of a statistical nature which will be further investigated and described in Section 4.

**Table 4. Summary of Basic Intersection Characteristics**

| Characteristic                            | High-Risk | Low-Risk | All Intersections |
|---|-----------|----------|-------------------|
| Speed Limit                               | 37.15     | 35.22    | 36.30             |
| Number of Lanes                           | 3.54      | 3.25     | 3.40              |
| Roadway Width (feet)                      | 78.86     | 69.79    | 78.71             |
| Sidewalk Segments (8 possible)            | 7.72      | 7.34     | 7.53              |
| Bike Lanes (4 possible)                   | 1.90      | 1.69     | 1.79              |
| Bus Stops (within ¼ mile)*                | 6.59      | 7.24     | 6.91              |
| Non-Residential Driveways (within ¼ mile) | 10.48     | 6.69     | 8.59              |
| Rail Stops (within ¼ mile)*               | 0.03      | 0.03     | 0.03              |
| Trails (within ¼ mile)                    | 0.21      | 0.38     | 0.47              |
| Freeway On/Off Ramps (within ¼ mile)      | 0.21      | 0.17     | 0.19              |

\*Source: Utah Transit Authority 2011

There were also differences between both intersection types with regard to signal and crossing characteristics (shown in Table 5). Low-risk intersections exhibited signal lengths that were nearly 16 seconds longer, as well as fewer through lanes per segment and almost twice the rate of raised center medians.

**Table 5. Summary of Signal and Crossing Characteristics**

| Characteristic                                  | High-Risk | Low-Risk |
|---|-----------|----------|
| Signal Length (seconds)                         | 38.69     | 54.39    |
| Left Turn Arrows                                | 84.5%     | 71.75%   |
| Dedicated Left Turn Lanes (intersection total)  | 4.17      | 4.17     |
| Dedicated Right Turn Lanes (intersection total) | 2.72      | 2.38     |
| Through Lanes (per segment)                     | 1.84      | 1.72     |
| Raised Center Medians                           | 6.9%      | 13.8%    |
| Pedestrian Countdowns                           | 75.9%     | 73.9%    |
| Countdown Length (seconds)                      | 17.55     | 17.04    |

Lastly, there were several notable differences in built environment characteristics between the low- and high-risk intersections. Fewer high-risk intersections had trees planted in center medians or park strips, and high-risk intersections were more frequently located in commercial areas with buildings located slightly closer to the street (as shown in Table 6 below).

**Table 6. Summary of Built-Environment Characteristics**

| Characteristic           | High-Risk                         | Low-Risk                           |
|--------------------------|-----------------------------------|------------------------------------|
| Street Trees             | 20.7%                             | 24.1%                              |
| Sidewalk Width (feet)    | 6.13                              | 7.18                               |
| Building Setbacks (feet) | 107.66                            | 111.31                             |
| Land-Use*                | 3.4% Res<br>75.9% Com<br>20.7% MU | 10.3% Res<br>58.6% Com<br>31.0% MU |

\*Res= Residential Land Use, Com=Commercial Land Use, MU= Mixed-Use

### 3.4.3 Local Demographics

As was briefly described in the literature review, two main groups have shown significant vulnerability and higher rates of non-motorized accident involvement; the young (ages 18 and under) and the elderly (ages 65 and over). Individuals in these groups are statistically more likely to be involved in a non-motorized crash than adults ages 18-64. Therefore, this analysis sought to determine the percentage of population within ¼ mile of each target intersection that identified with these age groups. It is hypothesized that areas with a large percentage of persons in these two age groups may exhibit more pedestrian or cyclist accidents than areas with fewer members of these vulnerable groups.

Table 7 below shows basic demographic characteristics for each high-risk intersection included in the evaluation including the percentage of the population that identifies as age 18 and under or age 65 and over, as well as the median household income, which has been correlated to active mode usage rates, and the percentage of persons who identify as primarily “walking to work”, which also may be correlated to a higher rate of accident involvement.

**Table 7. Demographic Characteristics\* Near High-Risk Intersections**

| Intersection Coordinates            | City          | Median HH Income | % Pop < Age 18 | % Pop > Age 65 | % Walk to Work |
|-------------------------------------|---------------|------------------|----------------|----------------|----------------|
| <b>Weber County</b>                 |               |                  |                |                |                |
| 12th St. Washington Blvd            | Ogden         | \$34,755         | 31.40          | 9.30           | 3.90           |
| 1900 West 5600 South                | Roy           | \$56,880         | 34.20          | 8.00           | 0.00           |
| 4000 South Riverdale Rd.            | Riverdale     | \$43,347         | 30.80          | 6.10           | 1.60           |
| 25th St. Washington Blvd            | Ogden         | \$32,218         | 16.70          | 9.30           | 3.90           |
| 25th St. Wall Ave                   | Ogden         | \$32,218         | 16.70          | 9.30           | 0.00           |
| 1900 West 4400 South                | Roy           | \$44,267         | 26.50          | 19.80          | 1.10           |
| 1900 West 4800 South                | Roy           | \$44,267         | 26.50          | 19.80          | 1.10           |
| 42nd St. Harrison Blvd              | Ogden         | \$61,838         | 24.30          | 17.30          | 3.20           |
| 30th St. Harrison Blvd              | Ogden         | \$61,838         | 24.30          | 17.30          | 3.20           |
| 2600 North Washington Blvd          | North Ogden   | \$66,047         | 37.70          | 13.10          | 0.00           |
| <b>Davis County</b>                 |               |                  |                |                |                |
| Antelope Dr. Hillfield Rd.          | Layton        | \$56,530         | 31.4           | 5.3            | 4.4            |
| 500 South 200 West                  | Bountiful     | \$48,178         | 28.7           | 14.7           | 2.8            |
| 700 South State St                  | Clearfield    | \$43,858         | 36.20          | 6.20           | 0.60           |
| 2600 South Hwy 89                   | Bountiful     | \$55,150         | 27.30          | 17.60          | 2.90           |
| 500 South Main St                   | Bountiful     | \$48,178         | 28.70          | 14.70          | 2.80           |
| Hillfield Rd. and Main St.          | Layton        | \$53,449         | 35.00          | 6.60           | 0.90           |
| Antelope Dr. University Park Blvd.  | Layton        | \$45,870         | 21.90          | 5.70           | 0.60           |
| 2000 West Antelope Dr. (1700 South) | Syracuse      | \$74,310         | 41.00          | 4.10           | 0.20           |
| 1000 West Antelope Dr. (1700 South) | Syracuse      | \$67,098         | 38.40          | 3.80           | 2.00           |
| 300 North Main St.                  | Clearfield    | \$43,858         | 36.20          | 6.20           | 0.60           |
| <b>Utah County</b>                  |               |                  |                |                |                |
| Bulldog Blvd and University Ave.    | Provo         | \$17,259         | 1.50           | 0.00           | 34.10          |
| State St. and Center St.            | Orem          | \$38,519         | 31.30          | 8.90           | 0.90           |
| 800 South State St.                 | Orem          | \$32,372         | 38.40          | 3.20           | 0.00           |
| 200 North West State St.            | American Fork | \$67,083         | 32.00          | 9.50           | 1.60           |
| Bulldog Blvd and Hwy 89             | Provo         | \$41,269         | 24.50          | 7.10           | 5.60           |
| Freedom Blvd and Bulldog Blvd       | Provo         | \$17,259         | 1.50           | 0.00           | 34.10          |
| 1500-1600 South Center St.          | Orem          | \$47,128         | 25.50          | 11.50          | 2.70           |
| 1720 North State St.                | Orem          | \$36,125         | 15.50          | 3.50           | 9.10           |
| 800 North University Ave.           | Provo         | \$25,000         | 12.80          | 2.80           | 21.30          |
| <b>Mean=</b>                        |               | <b>\$46,074</b>  | <b>26.78</b>   | <b>8.98</b>    | <b>4.87</b>    |

\*Source: US Census 2010

Table 8 shows data similar to that presented in Table 7, for the low-risk intersection sample.

**Table 8. Demographic Characteristics\* Near Low-Risk Intersections**

| Intersection Coordinates          | City  | Median HH Income | % Pop < Age 18 | % Pop > Age 65 | % Walk to Work |
|-----------------------------------|-------|------------------|----------------|----------------|----------------|
| <b>Weber County</b>               |       |                  |                |                |                |
| 4600 South Harrison Blvd          | Ogden | \$91,296         | 23.90          | 14.40          | 4.00           |
| 12th St. Wall Ave                 | Ogden | \$34,755         | 31.40          | 9.30           | 3.90           |
| 25th St. Lincoln Ave              | Ogden | \$32,218         | 16.70          | 9.30           | 0.00           |
| 3535 West 5600 South              | Roy   | \$72,850         | 3.20           | 3.10           | 0.00           |
| 1900 West Riverdale Rd. (5300 S.) | Roy   | \$56,927         | 20.20          | 8.70           | 3.30           |
| 3100 West 4800 South              | Roy   | \$59,986         | 33.90          | 5.40           | 0.30           |

|                                 |             |                 |              |             |             |
|---------------------------------|-------------|-----------------|--------------|-------------|-------------|
| 5600 South Harrison Blvd        | Ogden       | \$62,793        | 25.50        | 16.00       | 1.80        |
| 900 West Riverdale Road         | Riverdale   | \$56,927        | 20.20        | 8.70        | 3.30        |
| 4th St. Washington Blvd         | Ogden       | \$27,267        | 28.00        | 11.20       | 3.90        |
| 22nd St. Grant Ave              | Ogden       | \$32,218        | 16.70        | 9.30        | 0.00        |
| <b>Davis County</b>             |             |                 |              |             |             |
| 1225 North Hillfield Rd         | Layton      | \$56,530        | 31.40        | 5.30        | 4.40        |
| Antelope and Woodland Park Blvd | Layton      | \$56,530        | 31.40        | 5.30        | 4.40        |
| 500 South 500 West              | Bountiful   | \$40,982        | 23.40        | 16.90       | 2.70        |
| Parrish Lane 400 West           | Centerville | \$64,813        | 30.40        | 11.40       | 3.00        |
| 200 North Main St               | Kaysville   | \$68,333        | 38.70        | 14.60       | 0.30        |
| Gordan Ave and Fairfield Rd     | Layton      | \$52,868        | 29.40        | 15.20       | 0.90        |
| 1000 East 1700 South (Antelope) | Layton      | \$42,902        | 26.80        | 6.60        | 0.90        |
| 1800 South Orchard Blvd         | Bountiful   | \$48,178        | 28.70        | 14.70       | 2.80        |
| 300 North 2000 West             | Clearfield  | \$68,375        | 31.70        | 4.80        | 1.20        |
| 1000 West 800 North             | Clearfield  | \$68,373        | 31.70        | 4.80        | 1.20        |
| <b>Utah County</b>              |             |                 |              |             |             |
| 1600 North State St             | Orem        | \$69,714        | 36.10        | 5.90        | 2.30        |
| 400 South State St.             | Orem        | \$57,596        | 30.30        | 14.20       | 8.50        |
| University Pkwy and Main St.    | Orem        | \$52,093        | 23.10        | 8.60        | 2.50        |
| 500 West 940 North              | Provo       | \$41,269        | 24.50        | 7.10        | 5.60        |
| 1850 N. State St                | Provo       | \$36,125        | 15.50        | 3.50        | 9.10        |
| 800 North 800 East              | Orem        | \$83,750        | 37.70        | 8.70        | 4.40        |
| Bulldog Blvd and Canyon Rd.     | Provo       | \$17,259        | 1.50         | 0.00        | 34.10       |
| Main St. and State St.          | Lehi        | \$67,083        | 32.00        | 9.50        | 1.60        |
| University Ave Center Street    | Provo       | \$26,250        | 31.50        | 0.40        | 13.50       |
| <b>Mean=</b>                    |             | <b>\$53,101</b> | <b>27.51</b> | <b>8.89</b> | <b>4.16</b> |

\*Source: US Census 2010

The data above shows that annual household income is slightly higher near the low-risk intersections, while the populations of vulnerable groups are almost identical. The percentage of individuals who report walking to work was slightly higher near the high-risk intersections.

### 3.4.4 The Presence of Construction

One transient characteristic that may be responsible for a rise in intersection danger is the presence of construction or rehabilitation efforts. Construction equipment can impair flow and limit pedestrian and cyclist visibility to motor vehicles, as well as hampering the bike-ped right-of-way. For each high-risk intersection, Table 9 below provides a timeline for the non-motorized incidents that occurred. Each incident is labeled by the non-motorized mode being used (bike or ped), and the crash severity. Construction dates for each intersection are given in the far right column along with the type of construction/repair that was taking place. Accidents which occurred during intersection construction/improvement efforts are highlighted.

**Table 9. High-Risk Intersection Incidents and Construction**

| Intersection Coordinates            | City          | Total Crashes | Construction Crashes | Construction Type*                       |
|-------------------------------------|---------------|---------------|----------------------|--|
| <b>Weber County</b>                 |               |               |                      |  |
| 1900 West 4400 South                | Roy           | 7             | 0                    |  |
| 1900 West 4800 South                | Roy           | 7             | 0                    |  |
| 1900 West 5600 South                | Roy           | 8             | 1                    | Pavement Rehab                           |
| 4040 South Riverdale Rd.            | Riverdale     | 8             | 0                    |  |
| 42nd St. Harrison Blvd              | Ogden         | 6             | 0                    |  |
| 30th St. Harrison Blvd<br>Ogden     | Ogden         | 6             | 0                    |  |
| 25th St. Wall Ave                   | Ogden         | 7             | 0                    |  |
| 12th St. Washington Blvd            | Ogden         | 12            | 1                    | Pavement Rehab,<br>Widening              |
| 25th Street Washington Blvd         | Ogden         | 8             | 1                    | Preservation,<br>Roadway                 |
| 2600 North Washington Blvd          | North Ogden   | 6             | 1                    | Preservation,<br>Roadway                 |
|                                     | <b>Total=</b> | <b>75</b>     | <b>4</b>             |  |
| <b>Davis County</b>                 |               |               |                      |  |
| 2600 South Hwy 89                   | Bountiful     | 11            | 1                    | Bonded Wearing<br>Course                 |
| 500 South 200 West                  | Bountiful     | 12            | 1                    | Asphalt Open<br>Graded Service<br>Course |
| 500 South Main St                   | Bountiful     | 11            | 0                    |  |
| Hillfield Rd. and Main St.          | Layton        | 10            | 2                    | Micro-surfacing,<br>Microseal            |
| Antelope Dr. Hillfield Rd.          | Layton        | 18            | 0                    |  |
| Antelope Dr. University Park Blvd.  | Layton        | 10            | 2                    | Open Graded Seal                         |
| 2000 West Antelope Dr. (1700 South) | Syracuse      | 9             | 2                    | Road Widen                               |
| 1000 West Antelope Dr. (1700 South) | Syracuse      | 9             | 1                    | Road Widen                               |
| 700 South State St                  | Clearfield    | 12            | 1                    | Microseal                                |
| 300 North Main St.                  | Clearfield    | 9             | 0                    |  |
|                                     | <b>Total=</b> | <b>111</b>    | <b>10</b>            |  |
| <b>Utah County</b>                  |               |               |                      |  |
| 200 North West State St.            | American Fork | 13            | 1                    | Preservation,<br>Roadway                 |
| State St and Center St.             | Orem          | 16            | 0                    |  |
| 800 South State St.                 | Orem          | 14            | 0                    |  |
| 1500-1600 South Center St.          | Orem          | 11            | 0                    |  |
| 1720 North State St.                | Orem          | 11            | 4                    | Preservation,<br>Widening                |
| Bulldog Blvd and Hwy 89             | Provo         | 13            | 3                    | Pavement Rehab                           |
| Freedom Blvd and Bulldog Blvd       | Provo         | 13            | 0                    |  |
| Bulldog Blvd and University Ave.    | Provo         | 17            | 13                   | Fiber Optic Cable<br>Pavement Rehab      |
| 800 North University Ave.           | Provo         | 10            | 5                    | Fiber Optic Cable                        |
|                                     | <b>Total=</b> | <b>118</b>    | <b>26</b>            |  |

\*Construction dates and classification provided by UDOT

Of the 234 incidents that took place at the high-risk intersections, 40 took place during the presence of road construction (17.1%). In the case of many intersections, construction did

not seem to have a significant impact on non-motorized safety. However, for two Utah County intersections (Bulldog Blvd and University Ave; 800 North and University Ave.) over half of non-motorized incidents occurred during the construction time period, suggesting a correlation. It is also compelling to note that those two intersections are the only ones in the sample that experienced Fiber Optic Cable Installation. At the low-risk comparison intersections, no crashes took place during construction.

### 3.4.5 Level of Service

The automobile level-of-service (LOS) described below (Tables 10-11) was computed using a volume to capacity ratio identified using the Wasatch Front Regional Council (WFRC) and Mountainland Association of Government's (MAG) regional travel model for each intersection. Because level of service was identified for each segment (2 per intersection; North-South and East-West) the numbers represented below are standardized by averaging the two. In essence, the numbers shown in Table 10 indicate what percentage of the maximum roadway capacity is currently being used at that intersection (i.e. .85 equals 85% of max capacity). In some instances, roadway segments exceeded design capacity therefore their LOS exceeded 1.0 or 100% (e.g. 1900 West 5600 South in Roy = 1.03).

For bicycle capacity, two measurements were used. Two level of service measurements were computed by WFRC for each road segment using the Bicycle Level of Service model (Sprinkle Consulting, Inc., 2007) and a Bicycle Compatibility Index (BCI) computed (also by WFRC) to reflect the comfort levels of bicyclists on the basis of observed geometric and operational conditions on a variety of roadways. Both of these methods are described in great detail, including derivations for each model, in the final report for the pilot study of this project (Burbidge, 2012).

Segment averaging was once again used to standardize the intersection measurements for the bicycle indices. For both the BLOS and BCI models a higher score means greater bicycle capacity. Tables 10 and 11 show the calculated Automobile LOS (defined as a volume/capacity ratio), Bicycle LOS, and the Bicycle Compatibility Index (BCI) for both the high-and low-risk

intersections. There is no non-motorized level of service data for Utah County as it falls under the jurisdiction of MAG and they do not compute these measures for their network.

**Table 10. High-Risk Intersections Level-of-Service**

| Intersection Coordinates            | City          | Auto LOS*   | Bicycle LOS              | BCI         |
|-------------------------------------|---------------|-------------|--------------------------|-------------|
| <b>Weber County</b>                 |               |             |                          |             |
| 12th St. Washington Blvd            | Ogden         | 0.57        | 2.80                     | 3.78        |
| 1900 West 5600 South                | Roy           | 1.03        | 4.42                     | 5.74        |
| 4000 South Riverdale Rd.            | Riverdale     | 0.58        | 3.81                     | 3.40        |
| 25th St. Washington Blvd            | Ogden         | 0.57        | 2.59                     | 3.71        |
| 25th St. Wall Ave                   | Ogden         | 0.56        | 4.66                     | 4.88        |
| 1900 West 4400 South                | Roy           | 0.64        | 3.88                     | 4.13        |
| 1900 West 4800 South                | Roy           | 0.59        | 2.27                     | 3.56        |
| 42nd St. Harrison Blvd              | Ogden         | 0.69        | 4.13                     | 4.13        |
| 30th St. Harrison Blvd              | Ogden         | 0.69        | 3.24                     | 3.69        |
| 2600 North Washington Blvd          | North Ogden   | 0.62        | 3.17                     | 3.56        |
| <b>Davis County</b>                 |               |             |                          |             |
| Antelope Dr. Hillfield Rd.          | Layton        | 0.83        | 3.24                     | 3.15        |
| 500 South 200 West                  | Bountiful     | 0.44        | 3.54                     | 3.52        |
| 700 South State St                  | Clearfield    | 0.65        | 3.35                     | 3.58        |
| 2600 South Hwy 89                   | Bountiful     | 0.60        | 3.90                     | 3.70        |
| 500 South Main St                   | Bountiful     | 0.31        | 3.69                     | 2.69        |
| Hillfield Rd. and Main St.          | Layton        | 0.74        | 3.44                     | 3.79        |
| Antelope Dr. University Park Blvd.  | Layton        | 0.83        | 3.57                     | 3.67        |
| 2000 West Antelope Dr. (1700 South) | Syracuse      | 0.50        | 3.74                     | 3.27        |
| 1000 West Antelope Dr. (1700 South) | Syracuse      | 0.74        | 3.45                     | 3.53        |
| 300 North Main St.                  | Clearfield    | 1.03        | 3.53                     | 4.38        |
| <b>Utah County</b>                  |               |             |                          |             |
| Bulldog Blvd and University Ave.    | Provo         | 0.44        | <i>No Data Available</i> |             |
| State St. and Center St.            | Orem          | 0.71        |                          |             |
| 800 South State St.                 | Orem          | 0.68        |                          |             |
| 200 North West State St.            | American Fork | 0.71        |                          |             |
| Bulldog Blvd and Hwy 89             | Provo         | 0.64        |                          |             |
| Freedom Blvd and Bulldog Blvd       | Provo         | 0.52        |                          |             |
| 1500-1600 South Center St.          | Orem          | 0.84        |                          |             |
| 1720 North State St.                | Orem          | 0.69        |                          |             |
| 800 North University Ave.           | Provo         | 0.74        |                          |             |
| <b>Mean=</b>                        |               | <i>0.66</i> | <i>3.52</i>              | <i>3.79</i> |

\* Source: WFRC and MAG, 2014

**Table 11. Low-Risk Intersections Level-of-Service**

| Intersection Coordinates          | City        | Auto LOS*   | Bicycle LOS              | BCI         |
|-----------------------------------|-------------|-------------|--------------------------|-------------|
| <b>Weber County</b>               |             |             |                          |             |
| 4600 South Harrison Blvd          | Ogden       | 0.40        | 1.87                     | 3.29        |
| 12th St. Wall Ave                 | Ogden       | 0.56        | 3.55                     | 4.23        |
| 25th St. Lincoln Ave              | Ogden       | 0.25        | 2.10                     | 2.19        |
| 3535 West 5600 South              | Roy         | 0.77        | 3.98                     | 3.78        |
| 1900 West Riverdale Rd. (5300 S.) | Roy         | 0.76        | 3.77                     | 4.36        |
| 3100 West 4800 South              | Roy         | 0.14        | 3.58                     | 2.94        |
| 5600 South Harrison Blvd          | Ogden       | 0.77        | 3.98                     | 3.77        |
| 900 West Riverdale Road           | Riverdale   | 0.89        | 4.09                     | 4.21        |
| 4th St. Washington Blvd           | Ogden       | 0.69        | 4.17                     | 4.41        |
| 22nd St. Grant Ave                | Ogden       | 0.17        | 3.36                     | 1.67        |
| <b>Davis County</b>               |             |             |                          |             |
| 1225 North Hillfield Rd           | Layton      | 0.52        | 3.61                     | 4.32        |
| Antelope and Woodland Park Blvd   | Layton      | 1.03        | 3.17                     | 2.79        |
| 500 South 500 West                | Bountiful   | 0.54        | 3.29                     | 4.61        |
| Parrish Lane 400 West             | Centerville | 0.55        | 3.39                     | 3.37        |
| 200 North Main St                 | Kaysville   | 0.69        | 3.89                     | 3.79        |
| Gordan Ave and Fairfield Rd       | Layton      | 0.41        | 2.82                     | 3.57        |
| 1000 East 1700 South (Antelope)   | Layton      | 0.93        | 2.72                     | 2.98        |
| 1800 South Orchard Blvd           | Bountiful   | 0.32        | 4.29                     | 3.27        |
| 300 North 2000 West               | Clearfield  | 0.68        | 4.20                     | 3.97        |
| 1000 West 800 North               | Clearfield  | 0.66        | 3.28                     | 2.93        |
| <b>Utah County</b>                |             |             |                          |             |
| 1600 North State St               | Orem        | 0.84        | <i>No Data Available</i> |             |
| 400 South State St.               | Orem        | 0.60        |                          |             |
| University Pkwy and Main St.      | Orem        | 0.71        |                          |             |
| 500 West 940 North                | Provo       | 0.78        |                          |             |
| 1850 N. State St                  | Provo       | 0.91        |                          |             |
| 800 North 800 East                | Orem        | 0.51        |                          |             |
| Bulldog Blvd and Canyon Rd.       | Provo       | 0.53        |                          |             |
| Main St. and State St.            | Lehi        | 0.89        |                          |             |
| University Ave Center Street      | Provo       | 0.45        |                          |             |
| <b>Mean=</b>                      |             | <i>0.59</i> | <i>3.33</i>              | <i>3.58</i> |

\* Source: WFRM and MAG, 2014

Although the original pilot study showed statistically significant differences in the Bicycle LOS and BCI measurements, a paired samples t-test of BLOS and BCI for this sample revealed no significant differences between the two measurement tools ( $t=1.54$ ,  $sig.=0.13$ ).

### 3.5 Summary

Using a GIS database, high- and low-risk intersections were identified. Geographically, high-risk intersections exhibit some clustering in each county, the most pronounced being in

Utah County. High-risk intersections had a higher average speed limit, wider street width, and had a higher number of non-residential driveways nearby. Additionally, low-risk intersections exhibited signal lengths that were nearly 16 seconds longer, as well as fewer through lanes per segment and almost twice the rate of raised center medians. Fewer high-risk intersections had trees planted in center medians or park strips, and high-risk intersections were more frequently located in commercial areas with buildings located slightly closer to the street

A look at demographics surrounding the intersections revealed that annual household income is slightly higher near the low-risk intersections, while the populations of vulnerable groups are almost identical. The percentage of individuals who report walking to work was slightly higher near the high-risk intersections. When examining the construction timeline for each intersection, the data show that for two high-risk intersections over half of non-motorized crashes occurred during a construction time period, while at the low-risk comparison intersections no crashes took place during construction.

Lastly, an examination of two different measures for bicycle compatibility/level of service revealed that although they significantly differed for intersection in the Salt Lake County Pilot Study, there is no statistically significant difference between the two measures in this sample.

## **4.0 DATA EVALUATION**

### **4.1 Overview**

The following section provides quantitative evaluations and analyses comparing the characteristics of the high- and low-risk intersections described in the sections above. This includes an evaluation of the relationship between accident rates and intersection characteristics, demographics, level of service variables, built environment measures, and the presence of construction. This section also looks at the relationship between intersection characteristics and accident severity for cyclists and pedestrians.

### **4.2 Comparison of High-Risk vs. Low-Risk Intersections**

The first goal of this research was to identify significant differences between high-risk and low-risk intersections. Prior to defining characteristic differences and to provide an additional level of statistical control, an independent samples t-test was run to identify that there is indeed a significant difference between the accident rates at high-risk versus low-risk intersections.

**Table 12. Comparison of Accident Rates at Intersections (t-test)**

|                         | <b>Means*</b>            | <b>Standard<br/>Deviation</b> | <b><i>t</i></b> | <b>Significance<br/>(<i>p</i>)</b> |
|-------------------------|--------------------------|-------------------------------|-----------------|------------------------------------|
| Non-Motorized Accidents | Low- 1.66<br>High- 10.52 | 1.396<br>3.236                | 13.541          | 0.000                              |
| Bicycle Accidents       | Low- 0.79<br>High- 5.97  | 0.861<br>3.134                | 8.571           | 0.000                              |
| Pedestrian Accidents    | Low- 0.79<br>High- 4.41  | 0.902<br>2.307                | 7.872           | 0.000                              |

\* Low=Low-risk intersections, High= High-risk intersections

In all cases, low-risk intersections experienced significantly lower rates of active-mode crashes than the high-risk intersections, even when controlling for the presence of construction (shown in table 12). This preliminary determination makes it possible to proceed in further identifying statistical differences between the low- and high-risk intersections identified in the prior sections.

#### 4.2.1 Demographics

First, an independent-samples t-test was employed to identify if the demographics of the areas immediately surrounding the intersections in question differed significantly between those classified as low- and high-risk. As shown in Table 13 below, there was no significant difference in the predictor demographics between the areas surrounding the low- and high-risk intersections in this sample.

**Table 13. Demographic Comparison of Surrounding Areas\* (t-test)**

|                | <b>Means**</b>                  | <b>Standard<br/>Deviation</b> | <b><i>t</i></b> | <b>Significance<br/>(<i>p</i>)</b> |
|----------------|---------------------------------|-------------------------------|-----------------|------------------------------------|
| HH Income      | Low- \$53,101<br>High- \$46,074 | \$17,816<br>\$14,585          | 1.643           | 0.106                              |
| % pop < age 18 | Low- 27.51<br>High- 26.78       | 7.90<br>10.09                 | 0.304           | 0.762                              |
| % pop > age 65 | Low- 8.893<br>High- 8.899       | 4.697<br>5.694                | -0.070          | 0.944                              |
| % Walk to Work | Low- 4.16<br>High- 4.87         | 6.523<br>9.075                | -0.344          | 0.732                              |
| % Bike to Work | Low- 0.99<br>High- 1.13         | 1.269<br>1.751                | -0.361          | 0.720                              |

\*All variable measurements are for households living within ¼ mile of the intersections studied

\*\* Low=Low-risk intersections, High= High-risk intersections

#### 4.2.2 Capacity Measures

Next, an independent-samples t-test was utilized to identify if the automobile and bicycle capacity measurements described in Section 3.4.5 differed significantly between intersections classified as low- versus high-risk. As a reminder automobile/motorized level of service was computed using a standardized volume to capacity ratio (V/C) while non-motorized level of service was determined using both the Bicycle Level of Service model (BLOS) and the Bicycle Compatibility Index (BCI). The analysis showed no significant differences between motorized levels of service. Neither the BLOS nor the BCI differed significantly between low- and high-risk intersections as well (Table 14).

**Table 14. Comparison of Level of Service Indices (t-test)**

|                             | <b>Means</b>              | <b>Standard Deviation</b> | <b><i>t</i></b> | <b>Significance (<i>p</i>)</b> |
|-----------------------------|---------------------------|---------------------------|-----------------|--------------------------------|
| Vehicle LOS (V/C Ratio)     | Low- 0.598<br>High- 0.661 | 0.217<br>0.158            | -1.243          | 0.219                          |
| Bicycle Level of Service    | Low- 3.531<br>High- 3.524 | 0.745<br>0.571            | 0.032           | 0.975                          |
| Bicycle Compatibility Index | Low- 3.585<br>High- 3.795 | 0.842<br>0.645            | -0.883          | 0.383                          |

#### 4.2.3 Design and Built Environment

Lastly, the characteristics of each intersection's design and surrounding built environment (summary statistics shown in Tables 4, 5, and 6) were run in an independent t-test analysis to determine if there was a statistically significant difference between the design of or built environments around low- versus high-risk intersections.

**Table 15. Comparison of Intersection Characteristics (t-test)**

| <b>Characteristic</b>                   | <b>Means</b>              | <b>Standard Deviation</b> | <b><i>t</i></b> | <b>Significance</b> |
|---|---------------------------|---------------------------|-----------------|---------------------|
| Speed Limit                             | Low- 33.70<br>High- 39.48 | 7.479<br>4.085            | -1.686          | 0.098               |
| Number of Lanes                         | Low- 3.26<br>High- 3.54   | 0.987<br>0.811            | -1.210          | 0.231               |
| Roadway Width (feet)                    | Low- 71.59<br>High- 85.83 | 23.793<br>17.903          | -2.576          | 0.013               |
| Sidewalk Segments (8 possible)          | Low- 7.34<br>High- 7.72   | 1.289<br>0.591            | -1.440          | 0.155               |
| Bike Lanes (4 possible)                 | Low- 1.69<br>High- 1.90   | 2.089<br>2.366            | -0.353          | 0.725               |
| Bus Stops (within ¼ mile)*              | Low- 7.24<br>High- 6.59   | 4.845<br>2.771            | 0.632           | 0.530               |
| Non-Residential Driveways (within 100m) | Low- 6.69<br>High- 10.48  | 5.211<br>5.275            | -2.755          | 0.008               |
| Rail Stops (within ¼ mile)*             | Low- 0.03<br>High- 0.03   | 0.186<br>0.186            | 0.000           | 1.000               |
| Trails (within ¼ mile)                  | Low- 0.38<br>High- 0.55   | 0.561<br>0.910            | -0.869          | 0.389               |

\*Source: Utah Transit Authority 2011

As Table 15 above shows there was a significant difference in the roadway width feeding into low-risk versus high-risk intersections. Low-risk intersections are significantly narrower than high-risk intersections. Additionally, the number of non-residential driveways (within 100 meters of the intersection) differed significantly between the low-and high-risk intersections with high-risk intersections having an average of four more per location.

A second test was conducted to examine the differences in signaling and crossing characteristics. An independent samples t-test revealed that high-risk intersections did have significantly more through lanes than the low-risk intersections (shown in Table 16). All other signal characteristics showed no significant differences in this sample.

**Table 16. Comparison of Signal and Crossing Characteristics (t-test)**

| Characteristic                                  | Means                       | Standard Deviation | <i>t</i> | Significance |
|---|-----------------------------|--------------------|----------|--------------|
| Signal Length (seconds)                         | Low- 54.39<br>High- 38.69   | 54.826<br>11.665   | 1.504    | 0.139        |
| Left Turn Arrows (1=yes, 0=no)                  | Low- 0.70<br>High- 0.83     | 0.470<br>0.384     | -1.133   | 0.271        |
| Dedicated Left Turn Lanes (Intersection Total)  | Low- 4.17<br>High- 4.17     | 1.338<br>1.197     | 0.000    | 1.000        |
| Dedicated Right Turn Lanes (Intersection Total) | Low- 2.38<br>High- 2.72     | 1.449<br>1.334     | -0.943   | 0.350        |
| Number of Through Lanes                         | Low- 1.72<br>High- 2.14     | 0.797<br>0.743     | -2.045   | 0.046        |
| Raised Center Medians (1=yes, 0=no)             | Low- 0.21<br>High- 0.14     | 0.491<br>0.441     | 0.562    | 0.576        |
| Pedestrian Countdowns                           | Low- 6.43<br>High- 6.28     | 2.889<br>3.184     | 0.186    | 0.853        |
| Countdown Length (seconds)                      | Low- 17.043<br>High- 17.557 | 4.212<br>5.107     | -0.397   | 0.699        |

None of the built environment characteristics significantly differed between low- and high-risk intersections within this sample (Table 17).

**Table 17. Comparison of Built-Environment Characteristics (t-test)**

| Characteristic           | Means                       | Standard Deviation      | <i>t</i>       | Significance |       |
|--------------------------|-----------------------------|-------------------------|----------------|--------------|-------|
| Street Trees             | Low- 0.24<br>High- 0.21     | 0.435<br>0.412          | 0.310          | 0.758        |       |
| Sidewalk Width (feet)    | Low- 7.18<br>High- 6.13     | 4.060<br>1.897          | 1.257          | 0.214        |       |
| Building Setbacks (feet) | Low- 111.31<br>High- 107.65 | 79.835<br>61.917        | 0.195          | 0.846        |       |
| Land-Use*                | Residential                 | Low- 0.10<br>High- 0.03 | 0.310<br>0.186 | 1.028        | 0.308 |
|                          | Commercial                  | Low- 0.59<br>High- 0.76 | 0.501<br>0.435 | -1.398       | 0.168 |
|                          | Mixed-Use                   | Low- 0.31<br>High- 0.21 | 0.471<br>0.412 | 0.890        | 0.377 |

\*Binary variable (1 = Yes, 0 = No) for each land-use type

### 4.3 Intersection Characteristics and Crash Rates

The analyses conducted in this section were applied for all intersections regardless of categorization (high-risk or low-risk). This allowed for direct relationships to be examined and identified between crash rates (all non-motorized together, as well as individual cyclist and pedestrian crashes) and characteristics, rather than relying on the simple comparative analyses presented in Section 4.2.

#### 4.3.1 Demographics

Table 13 in Section 4.2.1 compared the demographics of low- and high-risk intersections and found no significant differences. As shown in Table 18 below, a subsequent least-squares regression between surrounding area demographics and accident rates also revealed no highly significant correlations. Population under age 18 was closely correlated to bicycle crashes with an increase in that population resulting in an increase in bike crashes.

**Table 18. Correlation of Local Demographics and Crash Rates**

|  | $\beta$   | $t$    | <i>Sig.</i> |
|--|-----------|--------|-------------|
| <b>Total Non-Motorized Crashes</b>     |           |        |             |
| _Constant                              | 5.713     | 1.238  | 0.221       |
| HH Income                              | -0.343    | -1.892 | 0.064       |
| % pop < age 18                         | 0.179     | 1.398  | 0.168       |
| % pop > age 65                         | 0.006     | 0.037  | 0.971       |
| % Walk to Work                         | 0.153     | 1.076  | 0.287       |
| % Bike to Work                         | 0.039     | 0.079  | 0.937       |
| Model R <sup>2</sup> = 0.112      n=58 |           |        |             |
| <b>Bicycle Crashes</b>                 |           |        |             |
| _Constant                              | 0.939     | 0.312  | 0.756       |
| HH Income                              | -5.375E-5 | -1.472 | 0.147       |
| % pop < age 18                         | 0.162     | 1.948  | 0.057       |
| % pop > age 65                         | -0.039    | -0.383 | 0.703       |
| % Walk to Work                         | 0.170     | 1.838  | 0.072       |
| % Bike to Work                         | 0.265     | 0.824  | 0.414       |
| Model R <sup>2</sup> = 0.180      n=58 |           |        |             |
| <b>Pedestrian Crashes</b>              |           |        |             |
| _Constant                              | 4.359     | 1.891  | 0.064       |
| HH Income                              | -5.248E-5 | -1.876 | 0.066       |
| % pop < age 18                         | 0.017     | 0.267  | 0.790       |
| % pop > age 65                         | 0.078     | 1.009  | 0.318       |
| % Walk to Work                         | -0.003    | -0.037 | 0.970       |
| % Bike to Work                         | -0.287    | -1.167 | 0.248       |
| Model R <sup>2</sup> = 0.090      n=58 |           |        |             |

### 4.3.2 Bicycle Capacity Measures

A prior comparative analysis (Table 13) showed no significant differences between automobile LOS and BCI, as well as no significant differences in cyclist or pedestrian volumes during the time period measured between the high- and low-risk intersections. A follow-up correlation was performed that included motorized LOS as well as non-motorized LOS measures. Census data on walking and biking to work was also included in the model as a surrogate for volume counts. Because non-motorized level of service was not available for Utah County, this analysis only included intersections located in Weber and Davis Counties. The ordinary least-squares regressions similarly found no significant correlation between level of service (auto or bike), the BCI, non-motorized commuting, and crash rates (both comprehensive and mode specific). Results of the correlation analysis are displayed in Table 19 below.

**Table 19. Correlation of Level of Service Indices and Accident Rates**

|                | $\beta$                       | $t$    | $Sig.$   |
|----------------|-------------------------------|--------|----------|
|                | Total Non-Motorized Accidents |        |          |
| _Constant      | 5.751                         | 1.122  | 0.270    |
| Auto LOS       | 8.243                         | 1.561  | 0.128    |
| Bike LOS       | -0.919                        | -0.606 | 0.549    |
| BCI            | -0.860                        | -0.540 | 0.593    |
| % Walk to Work | 0.495                         | 0.961  | 0.344    |
| % Bike to Work | 0.300                         | 0.320  | 0.751    |
|                | Model R <sup>2</sup> = 0.116  |        | $n=38^*$ |
|                | Bicycle Accidents             |        |          |
| _Constant      | 1.162                         | 0.426  | 0.673    |
| Auto LOS       | 3.800                         | 1.353  | 0.185    |
| Bike LOS       | -0.071                        | -0.088 | 0.930    |
| BCI            | -0.274                        | -0.324 | 0.748    |
| % Walk to Work | 0.169                         | 0.615  | 0.543    |
| % Bike to Work | -0.006                        | -0.013 | 0.990    |
|                | Model R <sup>2</sup> = 0.086  |        | $n=38^*$ |
|                | Pedestrian Accidents          |        |          |
| _Constant      | 4.274                         | 1.354  | 0.185    |
| Auto LOS       | 3.766                         | 1.158  | 0.255    |
| Bike LOS       | -0.756                        | -0.809 | 0.424    |
| BCI            | -0.469                        | -0.478 | 0.636    |
| % Walk to Work | 0.306                         | 0.963  | 0.342    |
| % Bike to Work | 0.316                         | 0.546  | 0.588    |
|                | Model R <sup>2</sup> = 0.103  |        | $n=38^*$ |

\* Non-motorized LOS measures were not available for Utah County

#### 4.3.3 Intersection/Built-Environment Characteristics

Next, statistical analyses were employed to identify which, if any, characteristics of the built environment were significantly correlated to crash rates at the target intersections (both low- and high-risk). The results of these analyses are shown in Tables 20, 21, and 22 below.

**Table 20. Correlation of Intersection Characteristics and Crash Rates**

|   | $\beta$ | $t$    | Sig.  |
|---|---------|--------|-------|
| <b>Total Non-Motorized Accidents</b>    |         |        |       |
| _Constant                               | 1.416   | 0.139  | 0.890 |
| Speed Limit                             | -0.097  | -0.607 | 0.547 |
| Number of Lanes                         | 0.168   | 0.135  | 0.893 |
| Roadway Width (feet)                    | 0.062   | 1.069  | 0.292 |
| Sidewalk Segments                       | 0.280   | 0.324  | 0.748 |
| Bike Lanes                              | 0.157   | 0.390  | 0.698 |
| Bus Stops (within ¼ mile)               | -0.146  | -0.663 | 0.511 |
| Non-Residential Driveways (within 100m) | 0.272   | 1.580  | 0.122 |
| Rail Stops (within ¼ mile)              | 0.277   | 0.067  | 0.947 |
| Trails (within ¼ mile)                  | -0.334  | -0.298 | 0.767 |
| Model R <sup>2</sup> = 0.194      n=58  |         |        |       |
| <b>Bicycle Accidents</b>                |         |        |       |
| _Constant                               | 4.017   | 0.577  | 0.567 |
| Speed Limit                             | -0.119  | -1.091 | 0.282 |
| Number of Lanes                         | 0.869   | 1.022  | 0.313 |
| Roadway Width (feet)                    | 0.029   | 0.726  | 0.472 |
| Sidewalk Segments (8 possible)          | -0.080  | -0.137 | 0.892 |
| Bike Lanes (4 possible)                 | 0.193   | 0.701  | .0488 |
| Bus Stops (within ¼ mile)               | -0.144  | -0.960 | 0.343 |
| Non-Residential Driveways (within 100m) | 0.202   | 1.720  | 0.093 |
| Rail Stops (within ¼ mile)              | 0.567   | 0.202  | 0.841 |
| Trails (within ¼ mile)                  | 0.615   | 0.804  | 0.426 |
| Model R <sup>2</sup> = 0.236      n=58  |         |        |       |
| <b>Pedestrian Accidents</b>             |         |        |       |
| _Constant                               | -2.961  | -0.567 | 0.574 |
| Speed Limit                             | 0.035   | 0.431  | 0.669 |
| Number of Lanes                         | -0.792  | -1.240 | 0.222 |
| Roadway Width (feet)                    | 0.024   | 0.807  | 0.424 |
| Sidewalk Segments (8 possible)          | 0.430   | 0.972  | 0.337 |
| Bike Lanes (4 possible)                 | -0.085  | -0.411 | 0.683 |
| Bus Stops (within ¼ mile)               | 0.007   | 0.066  | 0.948 |
| Non-Residential Driveways (within 100m) | 0.062   | 0.711  | 0.482 |
| Rail Stops (within ¼ mile)              | -0.253  | -0.120 | 0.905 |
| Trails (within ¼ mile)                  | -0.773  | -1.346 | 0.186 |
| Model R <sup>2</sup> = 0.174      n=58  |         |        |       |

An ordinary least-squares regression analysis including the inventoried intersection characteristics revealed no significant correlation to crash rates. This lack of significance applied to both the aggregate active-mode crashes as well as the mode specific rates (bicycle or pedestrian).

**Table 21. Correlation of Signal and Crossing Characteristics and Crash Rates**

|                                      | $\beta$ | $t$    | Sig.  |
|--------------------------------------|---------|--------|-------|
| <b>Total Non-Motorized Accidents</b> |         |        |       |
| _Constant                            | 1.973   | 0.607  | 0.548 |
| Signal Length (seconds)              | -0.139  | -2.063 | 0.046 |
| Left Turn Arrows                     | 5.477   | 2.038  | 0.048 |
| Dedicated Left Turn Lanes            | -0.328  | -0.438 | 0.664 |
| Dedicated Right Turn Lanes           | -0.410  | -0.646 | 0.522 |
| Number of Through Lanes              | 3.459   | 2.928  | 0.006 |
| Raised Center Medians                | -1.431  | -0.959 | 0.343 |
| Pedestrian Countdowns                | 0.041   | 0.181  | 0.857 |
| Countdown Length (seconds)           | -0.111  | -0.577 | 0.567 |
| Model R <sup>2</sup> = 0.299 n=58    |         |        |       |
| <b>Bicycle Accidents</b>             |         |        |       |
| _Constant                            | 0.175   | 0.082  | 0.935 |
| Signal Length (seconds)              | -0.105  | -2.365 | 0.023 |
| Left Turn Arrows                     | 4.079   | 2.306  | 0.026 |
| Dedicated Left Turn Lanes            | -0.042  | -0.085 | 0.933 |
| Dedicated Right Turn Lanes           | -0.106  | -0.254 | 0.801 |
| Number of Through Lanes              | 2.743   | 3.528  | 0.001 |
| Raised Center Medians                | -0.209  | -0.212 | 0.833 |
| Pedestrian Countdowns                | 0.095   | 0.644  | 0.524 |
| Countdown Length (seconds)           | -0.220  | -1.741 | 0.089 |
| Model R <sup>2</sup> = 0.380 n=58    |         |        |       |
| <b>Pedestrian Accidents</b>          |         |        |       |
| _Constant                            | 1.678   | 0.936  | 0.355 |
| Signal Length (seconds)              | -0.034  | -0.904 | 0.372 |
| Left Turn Arrows                     | 1.539   | 1.038  | 0.305 |
| Dedicated Left Turn Lanes            | -0.437  | -1.059 | 0.296 |
| Dedicated Right Turn Lanes           | -0.249  | -0.712 | 0.481 |
| Number of Through Lanes              | 0.583   | 0.895  | 0.376 |
| Raised Center Medians                | -1.129  | -1.373 | 0.178 |
| Pedestrian Countdowns                | -0.040  | -0.326 | 0.746 |
| Countdown Length (seconds)           | 0.152   | 1.439  | 0.158 |
| Model R <sup>2</sup> = 0.165 n=58    |         |        |       |

An additional ordinary least-squares regression analysis found that several signal and crossing characteristic were significantly correlated to crash rates. Signal length, left turn arrows, and the number of through lanes each significantly correlated to crash rates. Each additional 10 seconds of signal length resulted in one less bicycle crash at a given intersection. Astoundingly, the presence a dedicated left turn signal arrow resulted in an additional 4 bicycle

crashes per intersection. Typically a green turn arrow is considered to promote driver safety by ensuring a protected signal phase, however, it makes the intersection more dangerous for pedestrians and cyclists. This concept is described in greater detail in Sections 5 and 6 of this report. The most significant correlation in the analysis revealed that each additional lane traveling through an intersection will result in nearly three additional bicycle crashes at the site. Each of these variables was also significantly correlated to total crashes. The majority of this cumulative correlation was likely due to the strong correlation to bicycle crash rates described above, however, the increase in Beta coefficients shows that pedestrian crashes were impacted as well, even though they were not significantly impacted in the mode specific model.

**Table 22. Correlation of Built-Environment Characteristics and Crash Rates**

|  | $\beta$ | $t$    | Sig.  |
|--|---------|--------|-------|
| <b>Total Non-Motorized Accidents</b>   |         |        |       |
| _Constant                              | 9.642   | 4.517  | 0.000 |
| Street Trees                           | -0.786  | -0.431 | 0.668 |
| Sidewalk Width (feet)                  | -0.275  | -1.102 | 0.276 |
| Building Setbacks (feet)               | -0.003  | -0.358 | 0.722 |
| Land Use-Residential                   | -4.740  | -1.793 | 0.079 |
| Land Use- Mixed                        | -3.289  | -2.189 | 0.033 |
| Model R <sup>2</sup> = 0.153      n=58 |         |        |       |
| <b>Bicycle Accidents</b>               |         |        |       |
| _Constant                              | 6.106   | 4.182  | 0.000 |
| Street Trees                           | -0.710  | -0.569 | 0.572 |
| Sidewalk Width (feet)                  | -0.213  | -1.248 | 0.218 |
| Building Setbacks (feet)               | -0.004  | -0.670 | 0.506 |
| Land Use-Residential                   | -2.379  | -1.315 | 0.194 |
| Land Use- Mixed                        | -1.970  | -1.916 | 0.061 |
| Model R <sup>2</sup> = 0.138      n=58 |         |        |       |
| <b>Pedestrian Accidents</b>            |         |        |       |
| _Constant                              | 3.317   | 3.021  | 0.004 |
| Street Trees                           | -0.088  | -0.093 | 0.926 |
| Sidewalk Width (feet)                  | -0.050  | -0.389 | 0.699 |
| Building Setbacks (feet)               | 0.001   | 0.171  | 0.865 |
| Land Use-Residential                   | -2.178  | -1.601 | 0.115 |
| Land Use- Mixed                        | -1.171  | -1.514 | 0.136 |
| Model R <sup>2</sup> = 0.079      n=58 |         |        |       |

\* Commercial land-use was removed from the model due to co linearity with the other land-use variables

Lastly, an ordinary least-squares regression including built environment characteristics revealed that mixed land-use significantly reduced the number of non-motorized crashes at an intersection by over three (3.28) incidents per site.

#### 4.3.4 Construction

Table 12 in Section 4.2 reported a significant difference in the number of construction related accidents that occurred in high-risk versus low-risk intersections, with high-risk intersections experiencing more construction related non-motorized accidents. However, the total impact of construction was not identified in that comparative analysis. To more fully explore the relationship between construction and non-motorized crashes an ordinary least-squares regression was run using an elasticity of the number of crashes occurring during construction as a predictor of total crash rates, including census non-motorized commute data as a surrogate for pedestrian and cyclist volume as controls.

**Table 23. Construction Impact on Crash Rates**

|  | $\beta$ | $t$    | Sig.  |
|--|---------|--------|-------|
| <b>Total Non-Motorized Crashes</b>     |         |        |       |
| _Constant                              | 5.296   | 6.765  | 0.000 |
| Crashes During Construction            | 1.299   | 3.497  | 0.001 |
| % Walk to Work                         | -0.044  | -0.475 | 0.637 |
| % Bike to Work                         | 0.090   | 0.212  | 0.833 |
| Model R <sup>2</sup> = 0.217      n=58 |         |        |       |
| <b>Bicycle Crashes</b>                 |         |        |       |
| _Constant                              | 2.538   | 5.139  | 0.000 |
| Crashes During Construction            | 1.001   | 4.273  | 0.000 |
| % Walk to Work                         | -0.014  | -0.238 | 0.813 |
| % Bike to Work                         | 0.201   | 0.749  | 0.457 |
| Model R <sup>2</sup> = 0.322      n=58 |         |        |       |
| <b>Pedestrian Crashes</b>              |         |        |       |
| _Constant                              | 2.708   | 6.364  | 0.000 |
| Crashes During Construction            | 0.309   | 1.529  | 0.132 |
| % Walk to Work                         | -0.028  | -0.541 | 0.591 |
| % Bike to Work                         | -0.182  | -0.786 | 0.435 |
| Model R <sup>2</sup> = 0.049      n=58 |         |        |       |

The model found that the presence of construction incidents among non-motorized travel modes significantly predicted an increase in aggregate non-motorized crashes as well as a significant increase in cycling crashes (Table 23 above). This implies that the presence of construction creates a significant hazard for non-motorized modes, specifically for cyclists.

#### 4.4 Intersection Characteristics and Crash Severity

A final analysis sought to identify if any of the above described intersection, signal/crossing, or built environment variables were significantly correlated to the severity of the non-motorized accidents that occurred during the measured time period. The hypothesis being that even if a variable does not increase the number of incidents, it may concomitantly result in more severe accidents when they do occur.

**Table 24. Correlation of Intersection Characteristics and Crash Severity**

|  | $\beta$                      | $t$    | <i>Sig.</i> |
|--|------------------------------|--------|-------------|
| <b>Total Non-Motorized Accidents</b>     |                              |        |             |
| _Constant                                | 0.967                        | 0.155  | 0.878       |
| Speed Limit                              | -0.045                       | -0.464 | 0.646       |
| Number of Lanes                          | -1.678                       | -0.646 | 0.523       |
| Roadway Width (feet)                     | 0.041                        | 1.363  | 0.183       |
| Sidewalk Segments                        | 0.139                        | 0.255  | 0.800       |
| Bike Lanes                               | -0.223                       | -0.936 | 0.357       |
| Bus Stops (within ¼ mile)                | 0.086                        | 0.614  | 0.544       |
| Non-Residential Driveways (within 100 m) | -0.027                       | -0.195 | 0.846       |
| Rail Stops (within ¼ mile)               | -1.081                       | -0.387 | 0.701       |
| Trails (within ¼ mile)                   | -0.756                       | -1.151 | 0.259       |
| Signal Length (seconds)                  | -0.032                       | -0.651 | 0.520       |
| Left Turn Arrows                         | 2.563                        | 1.277  | 0.212       |
| Dedicated Left Turn Lanes                | 0.055                        | 0.067  | 0.947       |
| Dedicated Right Turn Lanes               | -0.078                       | -0.119 | 0.906       |
| Number of Through Lanes                  | 0.324                        | 0.210  | 0.835       |
| Raised Center Medians                    | -2.018                       | -1.907 | 0.066       |
| Pedestrian Countdowns                    | 0.006                        | 0.044  | 0.965       |
| Countdown Length (seconds)               | 0.022                        | 0.166  | 0.869       |
|  | Model R <sup>2</sup> = 0.344 |        | n=58        |

However, as shown above (Table 24) an ordinary least-squares regression revealed no significant correlations between any of the site characteristics and accident severity for active modes. A close correlation was revealed between the presence of raised center medians and reduced crash severity, however it did not quite reach the .05 significance threshold.

#### 4.5 Summary

Comparison analyses revealed that in all cases, low-risk intersections experienced significantly lower rates of active-mode crashes than the high-risk intersections, even when controlling for the presence of construction. There was no significant difference in demographic

characteristics within 1/4 mile of the high-risk versus low-risk intersections and level of service measures (both auto and bicycle) were comparable between both intersections types. Statistical comparisons revealed that high-risk intersections are significantly wider (on average 14 feet) and have significantly more through lanes than low-risk intersections. Additionally, the presence and number of non-residential driveways is significantly higher near high-risk intersections (4 more on average within 100 meters) than low-risk intersection.

Regression analyses showed no significant correlation between an area's demographics and the non-motorized crash rates, as well as no significant correlation between level of service (auto or bike), the BCI, non-motorized volumes, and crash rates. Several signal characteristics were found to significantly impact crash rates. Intersections with shorter signal lengths (green light time) had significantly more cumulative non-motorized crashes and bicycle crashes. Intersections with more left turn arrows and through lanes were also found to have higher non-motorized and bicycle crash rates. Land-use was a significant predictor of safety as well. Areas with mixed land-use exhibited significantly fewer pedestrian crashes. Lastly, the presence of construction incidents among non-motorized travel modes significantly predicted an increase in aggregate non-motorized accidents as well as a significant increase in bicycle incidents implying that the presence of construction creates a significant hazard for non-motorized modes, specifically for cyclists. There were no significant correlations between any of the site characteristics and accident severity for active modes.

## **5.0 CONCLUSIONS**

### **5.1 Summary**

This section provides a condensed summary of the research presented in the prior sections as well as providing commentary surrounding the potential reasoning behind the results. This section concludes by providing a segue into the recommendations section which follows.

### **5.2 Findings**

#### **5.2.1 The Impact of Intersection Characteristics on Crash Rates**

The analysis presented in the previous sections addressed many of the characteristics and issues concerning differences between high- and low-risk intersections for pedestrians and cyclists, and identified which characteristics are the most significant at predicting non-motorized crash rates.

While the high- and low-risk intersections seem to have an even spatial dispersion throughout the study area, this research identified that high-risk and low-risk intersections do differ significantly in several ways. First, high-risk intersections are significantly wider than low-risk intersections. On average a high-risk intersection has an additional 14 feet of width. This additional width requires more time for non-motorized travelers to cross and could result in a failure to clear the intersection by the time the signal changes. High-risk intersections also have more through lanes than their low-risk counterparts. Intersection width and number of through lanes do however exhibit co-linearity due to the fact that an additional through lane would also make an intersection wider. Including both variables in the model (thereby controlling for their mutual exclusivity) resulted in only through lanes having a significant correlation to non-motorized crash rates. For each additional through lane that an intersection has the intersection will experience approximately three more non-motorized crashes (i.e. an intersection with three through lanes will have approximately six more non-motorized crashes than an intersection with only one through lane). Given these data the next significant factor should come as no surprise. Shorter signal lengths (green light times) result in a higher rate of

non-motorized crashes. Each additional 10 seconds of green light time results in 1.3 fewer non-motorized crashes. Taken in context a wider street with more through lanes is more dangerous to cross, and the likely culprit is that the signal time does not leave a pedestrian or cyclist with an adequate window to safely clear the intersection. Lengthening the signal time results in fewer crashes because cyclists and pedestrians are given a larger window in which to completely cross the right-of-way and clear the flow of traffic before the signal changes. As a final step to this analysis to fine tune the results shown, a "kitchen sink" regression model was run including all of the variables presented in this study simultaneously allowing a stepwise removal until only the strongest significance remained. This model showed that signal timing had the most significant impact on predicting non-motorized crashes. When co linearity was removed signal timing was still highly significant with each additional 10 seconds of signal time resulting in 1.5 fewer crashes ( $\beta = -0.151$ ,  $t = -2.178$ ,  $\text{sig.} = 0.035$ ).

One additional signaling variable that was found to significantly impact crash rates was the presence of green turn arrows. As the number of green turn arrows at intersections increased the number of non-motorized crashes increased dramatically. For each additional green arrow present in intersections in this sample, there was an increase of 5.47 non-motorized crashes. This is likely due to confusion in who has the right of way. According to the Utah Driver Handbook (UDPS, 2013), on a green arrow "vehicles turning left have the right-of-way and may make a 'protected' turn". However, that same guide also states that "vehicles turning right or left on a green light must yield the right-of-way to pedestrians who are in a marked or unmarked crosswalk within the intersection (UDPS, 2013)". Often these two rules are not considered equally in the mind of drivers and the visual cue of a green arrow alerts the driver that they have the right-of-way and they can proceed without having to worry about the presence of other vehicles or pedestrians. When an unexpected pedestrian or cyclist crossing the opposing lanes of traffic appears, it is difficult to stop. Pedestrians are also less likely to be educated about waiting to cross when the opposite traffic has a green arrow. Many pedestrians/cyclists may believe that because traffic is stopped on the lanes they are attempting to cross that they may proceed safely.

Finally, High-risk intersections exhibit a larger number of non-residential driveways within 100 meters of the intersection. Low-risk intersections had an average of 4 fewer non-

residential driveways within 100 meters. Non-residential driveways represent access to land-uses surrounding the intersection. Often, when cars are accessing the roadway within this critical 100 meter zone surrounding an intersection they pull out and immediately attempt to accelerate to acclimate to surrounding traffic speeds. If a car coming from one of these driveways turns toward the intersection and immediately accelerates, they are likely to exhibit a slower reaction if a pedestrian or cyclist suddenly appears in front of them at the intersection. Because they are often already in the process of accelerating, their behavior change to decelerate or "slam on their brakes" will be delayed and could easily result in a collision with the person crossing the street.

### 5.2.2 The Impact of Demographics on Crash Rates

The second major question posed in this research was do areas with specific demographics experience more/less bicycle and pedestrian accidents (e.g. a large percentage of young people)? As shown in Section 4, demographics were not significantly correlated to crash rates for either aggregate or specific active modes. While there was some variation in the demographics at high-risk versus low-risk intersections, the differences were not significant. Additionally, a regression analysis of demographics revealed no significant correlation between the type of households living within ¼ mile of the intersection and the number of active mode accidents.

### 5.2.3 The Impact of Built-Environment Characteristics on Accident Rates

The final question addressed by this research sought to identify which physical characteristics make intersections more dangerous for cyclists and pedestrians. Only one characteristic was significantly correlated to impact on the number of non-motorized crashes represented in this sample. Intersections located in mixed-use developments experienced significantly fewer pedestrian crashes than intersections surrounded by residential or commercial land-uses. This confirms a wealth of prior research stating that mixed use developments are more supportive or complimentary to pedestrians.

#### 5.2.4 The Impact of Construction on Crash Rates

A parallel regression analysis of elasticities found that the presence of non-motorized crashes during construction at a given intersection significantly predicted an increase in aggregate non-motorized accidents, as well as predicting a significant increase in cyclist incidents. This implies that the presence of construction creates a significant hazard for non-motorized modes, specifically for cyclists. This can happen due to reduced visibility, impediments to the sidewalks/shoulders, and restrictions in travel lanes.

### **5.3 Limitations and Challenges**

The major limitation faced by this research was its variation from the results of the pilot analysis of Salt Lake County (Burbidge, 2012). This research used a larger sample of intersections which provided more robust statistical validity (both internal and external) and allowed for a greater determination of statistical significance, however, it did not confirm the results initially revealed in that analysis.

It is unknown at this point if the difference in outcomes is simply due to the sample size or if geographic variation plays a role. It may be plausible that factors impacting safety in the more urban Salt Lake County significantly differ from those impacting the more suburban counties described in this analysis. One of the limitations described in the pilot study was a lack of geographic diversity. It was even argued that the analysis may differ if applied to a different geographic area such as Davis or Utah counties. Furthermore, there could be even more significant variation in areas outside the Wasatch Front in the more rural parts of Utah or even Southern Utah. A follow-up to this analysis will examine additional less urbanized areas of the state.

Additional analysis will be conducted in the future with a pooled dataset including all county data (Weber, Davis, Salt Lake and Utah) to determine which variables hold their significance when pooled as a sample of the entire Wasatch Front versus examining them individually by county.

## **6.0 RECOMMENDATIONS AND IMPLEMENTATION**

### **6.1 Recommendations**

Based upon the data and analysis presented in the previous sections, three key recommendations have been developed.

- Evaluate signal timing to better accommodate intersection width;
- Reduce conflicts on green arrows by avoiding left turn parallel path crashes; and
- Consider limiting the number of non-residential access points in the upstream functional area of an intersection (based on Utah's Administrative Code R930-6: Access Management)

#### **6.1.1 Signal Timing- Longer is Better**

The analysis section of this research presented in multiple ways that signal timing is a critical issue in predicting safety of non-motorized travelers. This manifest itself in the form of wider intersections being more dangerous, as well as intersections with more through lanes being more dangerous. When a comprehensive model was run to reduce co linearity all of these covariates basically boiled down to the impact of signal timing, and the fact that longer signals times make intersections safer for pedestrians and cyclists.

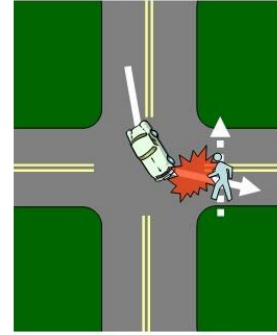
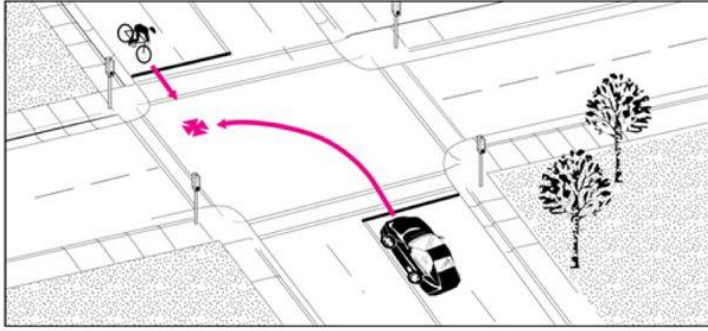
General walking speed results in an individual clearing 3 feet (.91 meters) per second (traveling approximately 2 miles per hour). Using one of our high-risk intersections as an example, let us examine a scenario. A pedestrian traveling south across the intersection at Antelope Dr. and University Park Blvd in Layton has exactly 30 seconds of green light (at peak) to cross eight lanes of traffic (86 feet). If that pedestrian entered the intersection at the exact moment the light turned green they would be able to cross the intersection in about 28 seconds at a moderate pace, leaving approximately 2 seconds until the end of the signal cycle. However, if that individual entered the intersection after the initial green light or if the pedestrian is mobility impaired they will not have enough time to get entirely across the intersection before the lights change.

This problem can be further exacerbated by the fact that the last lane of traffic that a pedestrian crosses at any given intersection is likely to be a right turn lane. Since it is legal to make a right turn on a red light (after first stopping to yield), cars in this lane may not be as observant to pedestrians or cyclists crossing the roadway. Many times, as soon as the light changes to green, cars in the right lane immediately proceed to turn without looking to ensure there are no pedestrians attempting to cross the last few feet of the intersection.

It is recommended that signal timing at intersections be calibrated based not only upon traffic flows, but also upon a minimum time frame based upon how long it would take an average person to cross. As green light times at peak are typically longer than at other times of the day it is incredibly likely that for the majority of the day the signal may not be providing an adequate amount of time for non-motorized modes to clear the intersection.

#### 6.1.2 Avoiding Conflict on Green Arrows

The analysis section of this report showed that for each additional green arrow that is present at an intersection in this sample, over five additional non-motorized crashes will take place. The greatest explanation for this is what is referred to as the "left turn parallel path" problem. This occurs when a pedestrian is waiting at the curb and the section of traffic he wants to cross is stopped at a red light. The pedestrian assumes that it is safe to enter the intersection without realizing that the oncoming lanes of traffic have a green arrow which will allow cars to turn directly into the lane that they are now inhabiting, as shown in Figure 8. As described above, drivers in this situation see that they have a "protected turn" and may not be fully aware of the potential presence of cyclists or pedestrians crossing. This problem can be easily remedied.

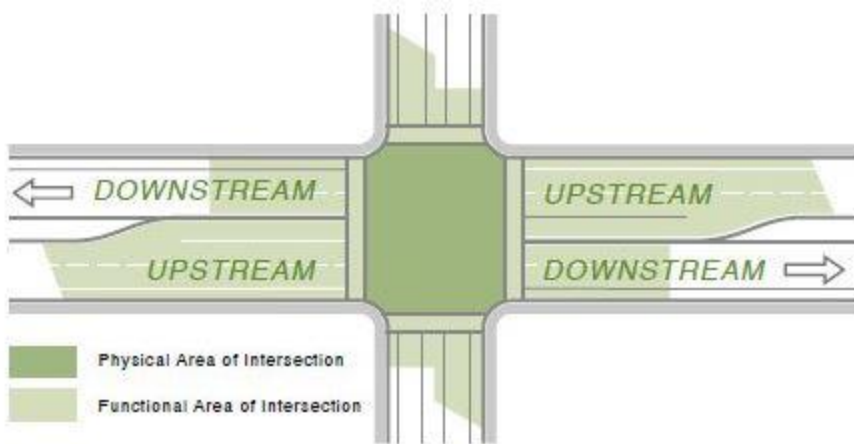


**Figure 8. Green Arrow Parallel Path Problem**

It is recommended that an educational or informational campaign be conducted focusing on pedestrians and their responsibilities as roadway users specifically regarding understanding and obeying signals and understanding right-of-way. It is highly likely that a large portion of the increased risk posed by green turn arrows is due to pedestrians who are crossing against the signal when they do not have the right-of-way. In that case, the automobile would not be at fault, but rather the pedestrian would have violated the law by misunderstanding when they have the legal right to cross.

### 6.1.3 Consider Limiting the Number of Non-Residential Drives Near Intersections

The last major recommendation of this research is to consider limiting the number of access points in the upstream functional area of the intersection. The American Association of State Highway and Transportation Officials' (AASHTO) "Policy On Geometric Design of Highways and Streets" defines upstream functional area of an intersection as a variable distance, influenced by: 1) distance traveled during perception-reaction time, 2) deceleration distance while the driver maneuvers to a stop, and 3) the amount of queuing at the intersection (AASHTO, 2004).



**Figure 9. Functional and Physical Areas of an Intersection (FHWA, 2010)**

The Federal Highway Administration (FHWA) strongly admonishes "limiting or, where possible, eliminating driveways within the functional area of an intersection (upstream and downstream) to help reduce the number of decisions motorists must make while traveling through an intersection and improve safety in the vicinity of an intersection". FHWA also recommends additional treatments to improve safety including adding median treatments (e.g. non-traversable medians), reducing driveway density, and placing sidewalks and pedestrian crossings so that pedestrians are most visible to drivers (FHWA, 2010).

Unfortunately the majority of safety recommendations from AASHTO and FHWA address the potential conflict with pedestrians at the non-residential driveways themselves, rather than looking at the implications of what happens just after a turn onto the adjacent roadway occurs. Therefore it is recommended that non-residential driveways be strictly limited within 100 feet of an intersection. This complies with portions of Utah Administrative Code R930-6 which addresses Access Management (UDOT, 2013) which states:

*The Department may require the review of the parking lot and circulation layout and require designs, terms, and conditions necessary to ensure the safe use of the access (UDOT, 2013, Section 4(i)ii(D) p. 24);*

and

*Access designs must provide for the safe and convenient movement of all highway right-of-way users and modes of transportation including but not limited to pedestrians, bicyclists, transit, and the physically challenged...(UDOT, 2013, Section 4(i)iii. p. 24).*

Additionally, design methods should be employed to reduce the number of opportunities for drivers to turn toward the intersection (into the upstream functional area) from these driveways, but rather traffic should be diverted into the downstream functional area. This type of design would likely provide an opportunity for employing new innovative intersection techniques to improve motorized traffic flow while also improving pedestrian and cyclist safety. It is also recommended that where appropriate a single driveway be provided to the adjacent roadway rather than multiple driveways to access the same development. This can create a funnel of traffic further from the intersection itself which will provide a great buffer and less potential for crashes with non-motorized modes.

It is anticipated the implementing these three major recommendations could dramatically improve bicycle and pedestrian safety at intersections in Utah.

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